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Design and Development of a Unified System for Detection of Life on Mars

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FOREWORD

This supplementary final report summarizes the design, fabrication, testing, and evaluation of components for a modularized engineering prototype of a Unified System for Detection of Life on Mars. This work was conducted by Martin Marietta Corporation for Ames Research Center, National Aeronautics and Space Administration, under Contract NAS2-7834.

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SUMMARY

Computer models of the Unified System thermal design were generated to simulate the thermal performance to be expected. These models were based on the thermal control concept which uses a heat exchanger to pump excess heat to a radiator on the outside of the lander during the Martian night and uses water as a phase change material to keep the test cells at a cool incubation temperature during the day. The test cells are individually heated for experiments requiring higher temperatures. The thermal environments calculated for a Viking '79 or '81 mission were used as inputs to the models with equipment mounting plate temperatures as high as 45°C in the hot case and as low as -23°C in the cold case.

A 71-node model was generated by the Martin Marietta Thermal Analysis System (MITAS) program to simulate the entire Unified System and its environments. This was used to generate a steady state determination of the boundary conditions for the incubator. These were then used as inputs for a 53-node model of the incubator for all the subsequent calculations of transient behavior. Models were also generated for the nutrient/reagent injector and for the cooling loop.

The models calculated a steady state analysis maximum heat load of 20 W into the incubator and showed that this can be reduced to 17 W by constructing the soil distribution assembly out of titanium rather than aluminum. The heat load results were used to derive a requirement for 1.33 kg of water with margin and 1.00 kg without margin. Transient analyses with the model confirmed reasonably well the estimates of the steady state analysis. A requirement of 29.3 W heat removal rate (which includes a 36% margin) by the cooling loop was derived from these results.

Calculations of the melting rate of ice in the individual modules was used to identify the need to reroute the wire bundle in the system and to verify that the cells would maintain their cooling through the entire Martian day. It was also shown that a three hour sterilization of a test cell at 160°C would not melt all the ice in the adjacent test cell modules.

The capability of the system to heat the soil uniformly in a test cell was investigated and found to require a central

heater in the cell. The injector heater was found by these calculations to be capable of providing preinjection heating to provide adequate expulsion vapor pressure as well as providing sterilization heating.

Cooling loop analysis was used to obtain an operating design point of 5 kg/hr mass flow of nitrogen cooling gas in the loop constructed of 1.27 cm od tubing with a radiator length of 7.8 meters and mass of 0.44 kg.

A cold case environment analysis identified a maximum heating requirement of 11.9 W to keep the incubator up to incubator temperatures.

A test cell module was designed and built containing the functional elements necessary for one test cell. These included a test cell and seal,cell transport and seal mechanism, cap, three injectors, gas line to the gas sampling valve, water jacket, heaters, and temperature sensors. The water jacket was hollowed out in multicelluar configuration with expansion absorbers in order to accommodate the expansion of water during freezing and the pressurization during 125°C sterilization. The test cell and cap were constructed with heaters and temperature sensors installed. The cap was made with the capability of receiving three of the larger capacity (1 cm^3) injectors with a direct free flow fluid path.

The injector redesign included increasing the fluid volume, developing the isolator diaphram, developing the techniques for large quantity production of capsules, improvement of the heater bushing-connector assembly, addition of an actuation indicator, and enlargement of the fluid flow path. The diaphram technique involved brazing at 1000°C and gave uniformly good results. A total of 100 capsules were produced with tooling designed to insure fit within the tolerances and reliable rupture. The heater design demonstrated repeatability of operation.

The incubator was constructed with the heat exchanger coil and a gas analysis inlet manifold. Its present state of construction allows it to receive modules with ultimate capability for eleven.

In order to control the temperatures of the test cell and cap in the module, control the preheating and injector firing for the three injectors, and to control the operational sequence

of events, a complete thermal control circuit was designed. These circuits were fabricated in breadboard form and mounted on a 1 3/4 in. standard rack panel. The soil temperature control circuits used proportional controller designs from the Viking '75 biology and provide set points of 5°C, 70°C, 90°C, and 160°C with others easily added.

An injector sequence circuit has a PROM stored program for effecting the sequence of freeze test, preheat, and actuate for the injectors. Circuits are included also for driving all the heaters, for selecting which injector is to be actuated and for displaying the various temperatures in the module.

Performance tests with the new injectors were used to iterate the design and to determine the reliability of fluid delivery. Successful fluid delivery with yields ranging from 74.7% to 94.4% of the loaded fluid was obtained for sixteen capsules at test cell pressures ranging from 4 to 50 torr, while three tests at 100 torr gave questionable delivery.

A cooling system blower test demonstrated a conservative value of 1.3 W power requirement to operate the blower in achieving the required 29.3 W heat rejection. This was accomplished with a 59 gram blower motor and squirrel cage impeller operating in a pressurized system at 9.3 atm (9.4×10^5 Pa).

The assembled test cell module was successfully checked for leak tight water jacket, dimensional stability during freezing, vacuum tight test cell including injectors and gas sampling line, and electrical and mechanical function and fit. The total injector had a mass of 434.3 g.

The Viking '75 Upper Atmosphere Mass Spectrometer (UAMS) engineering model originally built by Dr. Nier at the University of Minnesota (UM) was transferred to this contract from the Viking contract and sent to the UM for modification for dual ion counting and Faraday current detection. The interfaces between the UM and Martin Marietta in the Mass Spectrometer subsystem were also defined.

An overall look at the electronic system for the Unified System was used to identify those circuits which still require development and to focus attention on tradeoff considerations in locating the thermal control circuits either in the electronics module, the incubator, or the test cell modules.

I. INTRODUCTION

As the two Viking orbiters and landers approach their summer of '76 rendezvous with Mars, the day for obtaining some preliminary information about the existence or lack of biological life on the Mars surface is nearing realization. On the basis of past experience with scientific exploration of a new subject, it is probable that the results from these first missions to the Mars surface will raise more questions than they answer. The purpose of the present study, as well as the preceding contract efforts, was to develop an instrument for the Viking mission with enough flexibility in its design to respond to a wide range of possibilities in anticipated results from the 1975 mission.

The instrument requirements were evolved from the wide range of biology and soil chemistry experiments devised and performed by Dr. Bessel Kok and Dr. Richard Radmer. These experiments were performed with a laboratory mass spectrometer as the basic sensor monitoring the evolution and uptake of gases from soil samples exposed to various conditions. The biology experiments represent a graded series of tests ranging from very general "inferential" experiments to specific metabolic probes. The design of any single test involves a balance between universality and sensitivity. The more general tests make few assumptions and impose few perturbations on the soil, leaving the possibility of responding to a wide range of life processes, but with somewhat limited sensitivity. On the other hand, a specific approach invokes specific assumptions and may impose severe environmental perturbations, such as the addition of a nutrient. This can be very sensitive if the correct choice is made. The potential soil chemistry experiments cover a wide range of wet chemistry tests that result in a gas output of some sort, such as sulfamic acid reduction of soil nitrates characterized by appearance of N_2O above the soil.

During a preceding study, Contract (NAS2-6921), the basic concept of this instrument was developed into a multiple test cell laboratory capable of performing a wide variety of experiments whose operational principle involves sampling the gas composition above enclosed soil samples by recording the mass spectra of the gases. That study identified all the major technology areas involved in the system and began development work on some of these. In the preceding part of the present contract, this development work was pursued across a broad front such that some development was done on all the pertinent major technologies. The concept of a coherent functioning total system always guided the efforts. A strong emphasis during the development of components and technologies was their integration into the whole system. Therefore, test setups and hardware were generally configured as closely as possible to

anticipated flight configuration and design. In particular, the mechanical, thermal, gas analysis, and electronic system designs all had mutually strong influences on each other.

A. OPERATIONAL CONCEPT OF THE UNIFIED SYSTEM

The basic design philosophy for the Unified System consists of four major factors:

1) Flexibility in accommodating a variety of biology and soil chemistry experiments whose basic phenomena involve gas exchange with the head space above a sealed Martian soil sample.

2) Hardware that makes maximum use of knowledge gained from successes and failures in previous space instrumentation and use of developed successful hardware and avoidance of problem components.

3) Simplicity of assembly and disassembly features for low cost in test and development phases.

4) Biologically and chemically inert materials in the soil containers and gas analysis path.

The operational concept of the system developed for these experiments, illustrated in Fig. I-1, involves an array of 11 test cells with selectable internal volumes ranging from 1 to 10 cm^3. Each cell can be loaded separately with Martian soil in 1 cm^3 increments with up to 8 cm^3 in a cell. Each cell can then be permanently sealed with its charge of Martian soil and atmosphere. The subsequent operation sequence on the sealed test cell depends on the details of the particular biology and/or soil chemistry experiments to be performed in that cell. The cap each cell is sealed to contains three sealed quartz capsules, each containing up to 1 cm^3 of whatever nutrients gases, and/or reagents are to be added to the soil in that cell. At the proper time, each of these capsules is ruptured by a mechanism that allows its contents to fall directly onto the soil.

The thermal control system can then be programmed to either maintain that cell at a cool incubation temperature of $10^{\circ}C \pm 10$, or heat it to temperatures as high as $160^{\circ}C$ for up to three hours. Longer heating periods at lower temperatures, as well as higher temperatures for shorter periods, can be provided.

Provision is made for particular specialty modifications for certain test cells whose experiments require them. Such specialty

provisions include admission of light to the cell for photosynthesis, removal of its Martian atmosphere for soil carbon analysis, and high rate heating.

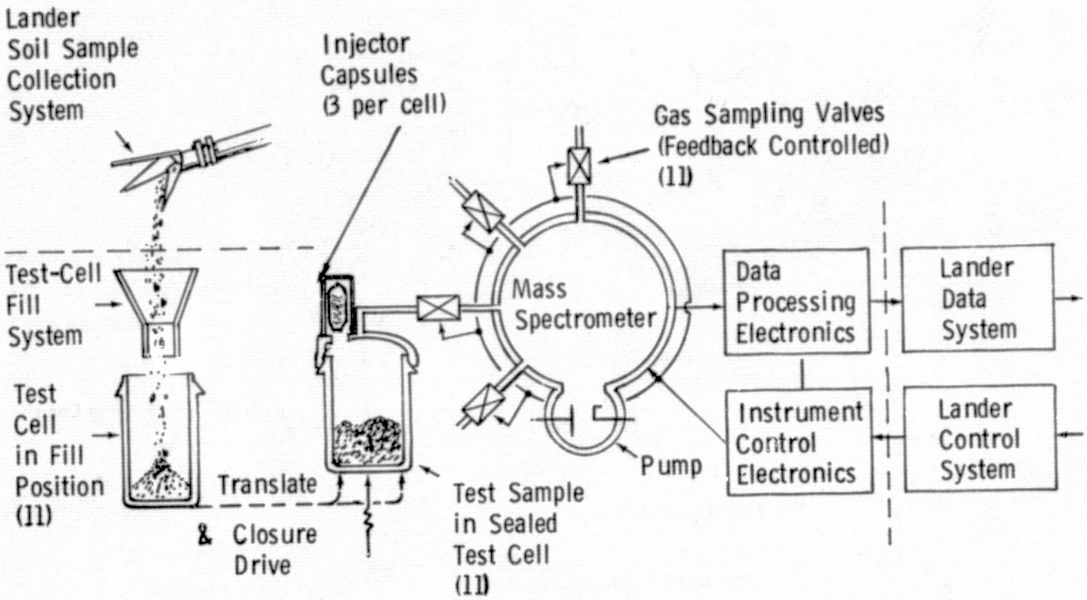


Fig. I-1 Operational Concept of Unified System

Each of the experiments performed in this Unified System manifests its results in the same way--by a detectable change in the chemical composition of the gas entrapped in the head space above the soil in the test cell. Each cell cap is, therefore, connected by way of a variable leak valve to the inlet manifold of a mass spectrometer, which accurately measures the relative quantity of each type of gas in the cell as the valve admits to it a tiny sample of the gas. In this way, quantitative details of the evolution and consumption of various gases by biota or chemical reactions in the soil can be accurately monitored.

The instrumentation concepts have been developed through an iterative process of system design and component engineering resulting in the system illustrated in Fig. I-2, which is composed of the following major subsystems: (1) mass spectrometer, (2) gas inlet, (3) incubator box, (4) test cell module (11 modules), (5) seal drive, (6) soil distribution, and (7) electronic control. The development approach has consisted of: (1) defining a system consistent with the requirements imposed by the anticipated biology and soil chemistry experiments, (2) identifying technologies and components necessary for the system, (3) building and testing those components that appeared the most critical, (4) using test results to modify the design, (5) reviewing the design for consistency with requirements as well as for hardware simplicity, reliability, and cost savings, and (6) reiterating these steps as necessary.

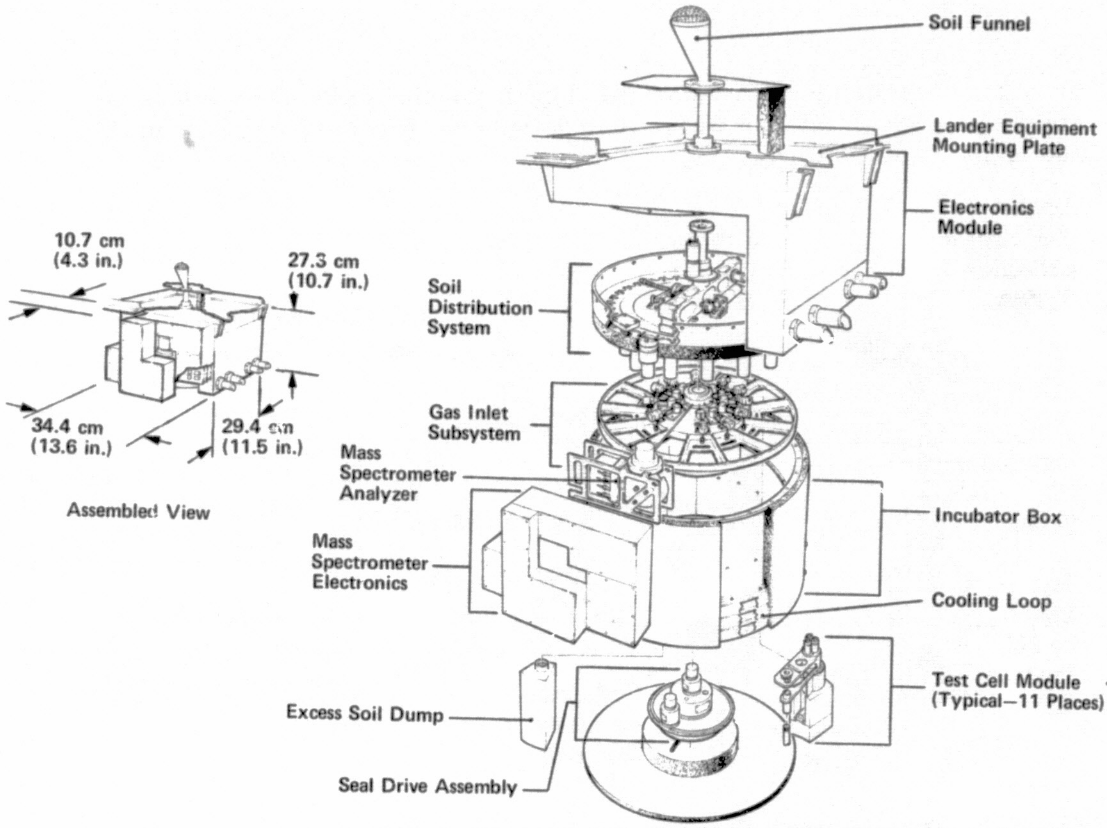


Fig. I-2 Basic Modular Assemblies for United System

B. SUPPLEMENTARY TASKS

The efforts of the contract supplement reported here were directed at consolidating some of the previous progress achieved in developing the engineering model for the earlier phases of this contract and in defining revised concepts for thermal control and modular configuration for an IR&D program. This effort concentrated on four tasks: (1) Thermal modeling and tests, (2) Test cell module, (3) Nutrient injector, and (4) Mass spectrometer prototype.

The first task consisted primarily of generating a computer thermal model of the entire system according to the revised thermal control concept and calculating various parameters such as heat loads, mass of phase change material (water) needed, radiator heat rejection rates, ice melting rates, soil heating rates and uniformity, and injector heating. It also involved running parametric performance characterization tests with coolant loop blowers.

The second task involved designing, fabricating, and testing a com-

plete test cell module as defined in the IR&D modular configuration concept. It included the design and fabrication of the incubator housing which serves as the structured assembly unit for all the test cell modules and for the gas analysis system. It also serves as a thermal incubation chamber for the test cell modules. Finally, the task included the design, fabrication, and function testing of a breadboard electronic system for thermal control of the test cell module. A design concept of the entire electronics for the Unified System was included in this electronic design.

The third task was aimed at modifying the design details of the injectors to rectify some problems encountered in testing of the first injector models and of testing the volume repeatability of the fluid delivery. The task also included developing procedures for repeatable manufacture of the injectors, the capsules, and for filling the capsules.

The fourth task involved acting on a decision made in the previous contract phase; i.e., to use a version of the mass spectrometer developed for atmosphere sampling missions by Dr. A.O.C. Nier at the University of Minnesota for the Unified System. We implemented this by transferring the engineering prototype of the Viking Upper Atmosphere Mass Spectrometer (UAMS) built by the University of Minnesota to this contract. Then we let a subcontract to the University of Minnesota to modify the instrument for use with the Unified System.

II. THERMAL MODELING

A. COMPUTER MODELS

The entire Unified System (Fig. I-2) was configured according to a thermal design concept developed as part of an IR&D program. The typical environments anticipated for a Viking '79 or '81 mission to Mars were used with this thermal design to generate computer models for calculating all the thermal parameters for the system.

1. Thermal Control Concept

The thermal control method is predicated on using a heat exchanger to pump excess heat to a radiator on the outside of the lander during the Martian night. It will use a phase change material (water/ice) to keep the test cells at a cool incubation temperature ($10^oC \pm 10$) during the day.

This concept has all the test cell modules contained in an incubator, as shown in Figure II-1, which has a minimum of internal heat sources and leakage paths. The heat exchanger cools the incubator, freezing the water contained in sealed water jackets which form the bases of each of the 11 test cell modules.

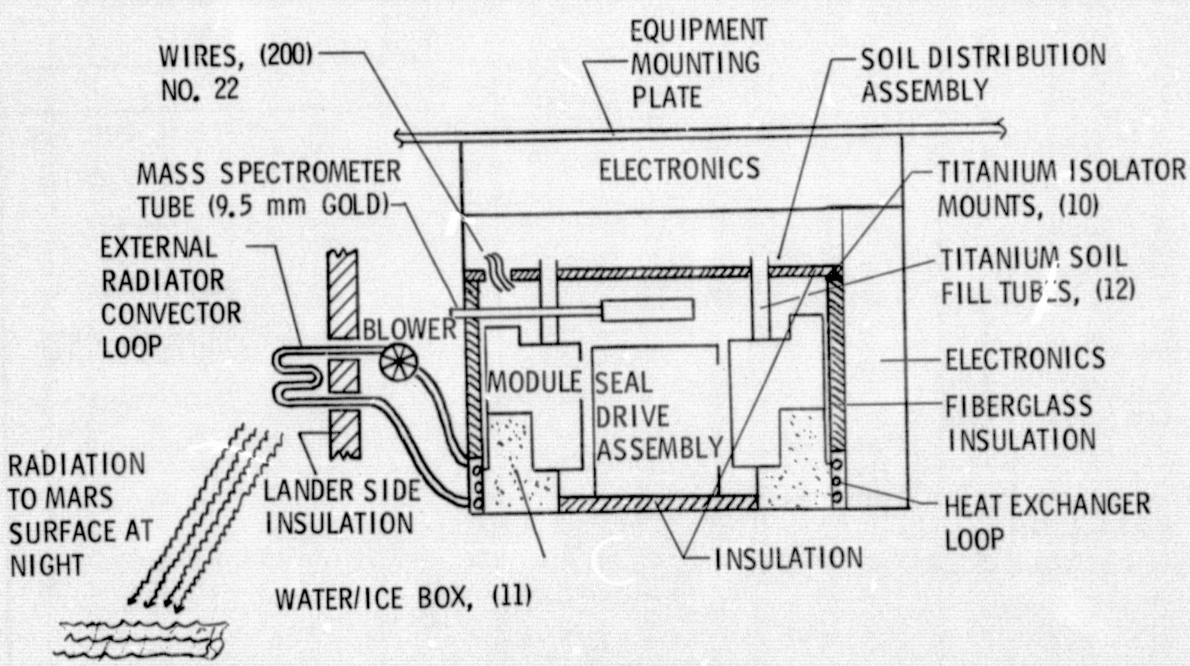
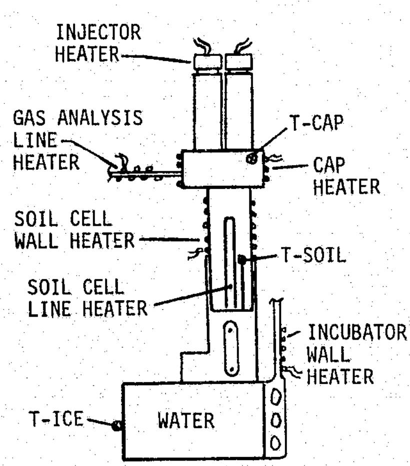


Fig. II-1 Thermal Control Features for Modular Configuration

When the test cell modules are installed in the incubator, their water jackets are attached firmly to the part of the incubator wall that is surrounded by the heat exchanger coil. The working fluid in the heat exchanger/radiator closed loop is gaseous N_2 at a pressure of approximately 10^6 N/m^2 (125 psig). It is circulated by a squirrel cage type blower.

Each test cell has a cal-rod type heater surrounding it and a platinum temperature sensor which forms the elements for the temperature control of the cell. The test cell cap has a similar heater and sensor. With these heaters, an individual test cell can be heated while all the remainder of the cells are maintained at the cooler incubation temperature. The ice in its water jacket absorbs the heat leakage from this heater. In addition, a test cell can be provided with a second heater mounted in a central tubular inversion in the test cell for providing a more uniform and rapid heating of the soil. The gas analysis tube leading from the test cell cap to the gas sampling valve connector has a heater wrapped around it to provide protection against condensation in the tube following a heating cycle. Each of the three injectors on the cap has a heater that serves to preheat the fluid in the injector for adequate expulsion pressure and to melt the spring retaining collar for actuation.

A set of thermal requirements were included in the thermal modeling to bracket any anticipated requirements. These are identified in Figure II-2.



MODE	DESCRIPTION
INCUBATION 10°C $+10$°C HOT AND NOM CASES	COOLING LOOP OPERATES AT NIGHT UNTIL T-10 <4°C FOR ALL MODULES MELTING ICE MAINTAINS DAYTIME INCUBATION
INCUBATION COLD CASE	INCUBATOR WALL HEATER MAINTAINS SOIL TEMPERATURE ABOVE 0°C
160°C STERILIZATION 160°C $^{+20}_{-0}$°C	SOIL CELL WALL HEATER PROPORTIONALLY CONTROLLED TO 160° BY T-SOIL. CAP HEATER, GAS ANALYSIS LINE HEATER, INJECTOR HEATERS CONTROLLED TOGETHER BY T-CAP.
70/90°C CONTROLLED HEATING 10 min TO TEMPERATURE, HOLD 24 hr ±1°C	SOIL CELL WALL HEATER PROPORTIONALLY CONTROLLED TO 90°C (OR 70°C) BY T-SOIL. CAP HEATER, GAS ANALYSIS LINE HEATER, SOIL CELL LINE HEATER POWERED TO PRESET VALUES.
NUTRIENT INJECTION A. PREINJECTION WARMUP B. PRESSURIZATION HEATING C. CAPSULE BREAKING	A. HEAT CAP AND SOIL TO 5°C B. POWER INJECTOR HEATER AT 1.4 W FOR TBD min. C. POWER INJECTOR HEATER AT 36 W FOR 40 sec.

Fig. II-2 Typical Thermal Control Requirements

These requirements show the inclusion of a heater for the incubator wall to accommodate the cold case environment for the Viking missions.

2. <u>Thermal Environments</u>

The primary thermal control task for this instrument is to hold the test cells that are incubating a biology experiment at a temperature simulating the anticipated environment just below the Martian soil surface where the biota are expected to have the best chance of living. To do this the test cells must be kept cooler than the temperatures of the Viking lander equipment mounting plate. This is illustrated in Figure II-3 which was calculated for a 1979 Viking mission. The curves for a 1981 mission have not been calculated, but the hot case temperatures for the equipment mounting plate (EMP) are expected to be very slightly less than for 1979.

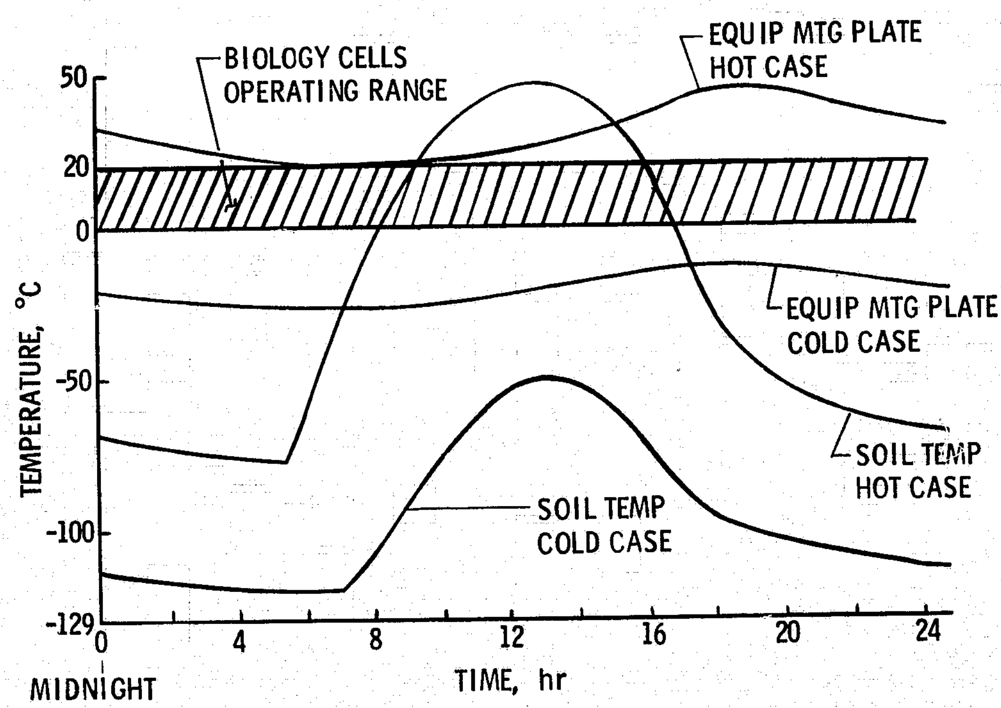


Fig. II-3 Viking'79 and '81 Mars Surface Environment

The EMP temperatures for the 1979 mission are about 5°C warmer than for the 1975 mission. The increase will be caused by the higher solar fluxes in 1979 when Mars will near its perihelion position (1.381 AU) compared with it being near its aphelion position (1.666 AU) during the 1975 mission. A 1981 mission would occur at slightly further than perihelion so we would ex-

pect slightly lower hot case temperatures, but not as low as for 1975.

Hot and cold case extremes are predicted by stacking maximum/minimum parameters in the lander thermal analyses. This problem is compounded for the advanced Viking mission because of the wide range of landing sites being considered.

3. <u>Thermal Analyses Programs Generated from MITAS</u>

The Martin Marietta Thermal Analysis System (MITAS) program was used to generate computer thermal models of this system as summarized in Figure II-4. The principle model was constructed with 71 thermal nodes and is based on the modular configuration described above.

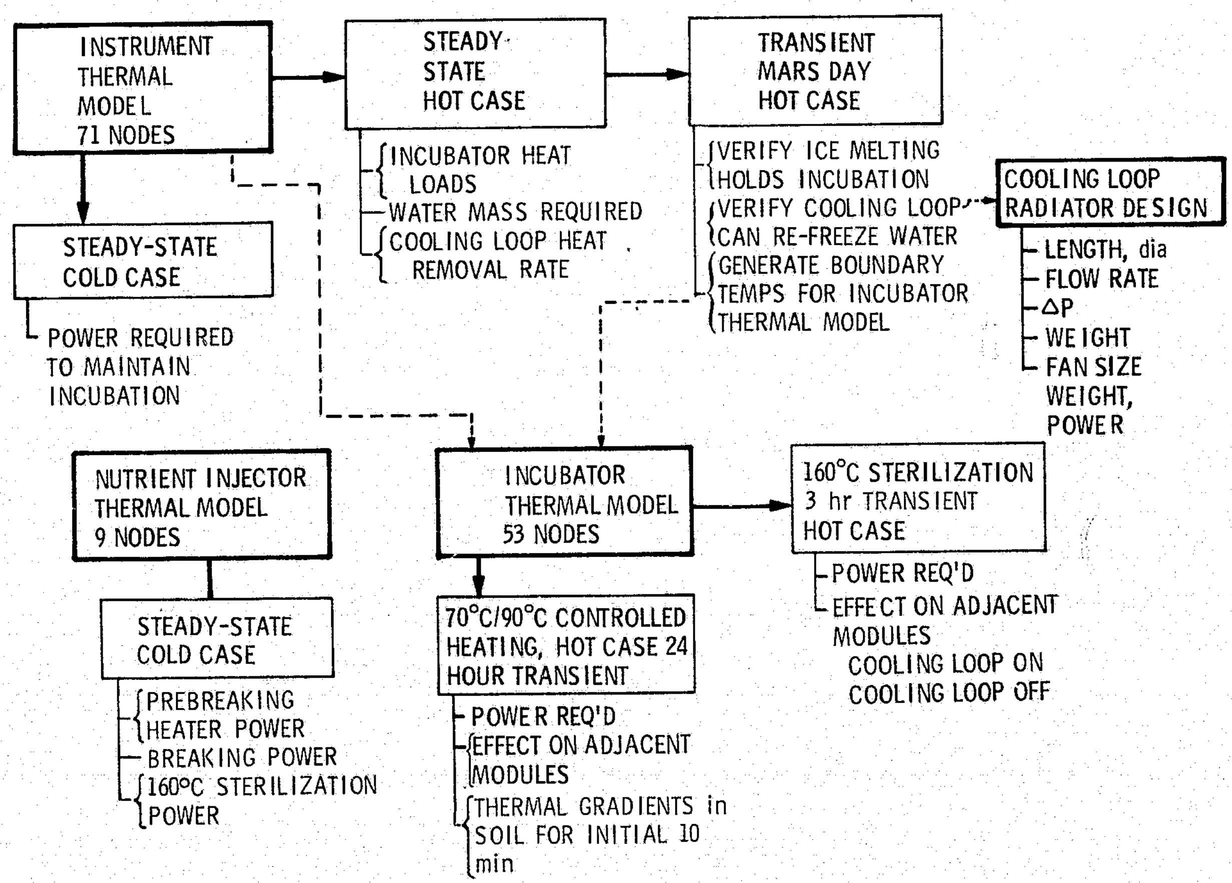


Fig. II-4 Thermal Modeling Summary

Forty of these nodes are in the thermal incubator. Six of those nodes are dedicated to the details of one test cell module. This model was then used to calculate parameters such as incubator heat loads, water mass required for thermal heat capacity, and cooling loop heat removal rate for hot case thermal environments in steady-state. The distribution of nodes throughout the Unified System configuration is shown in Figure II-5.

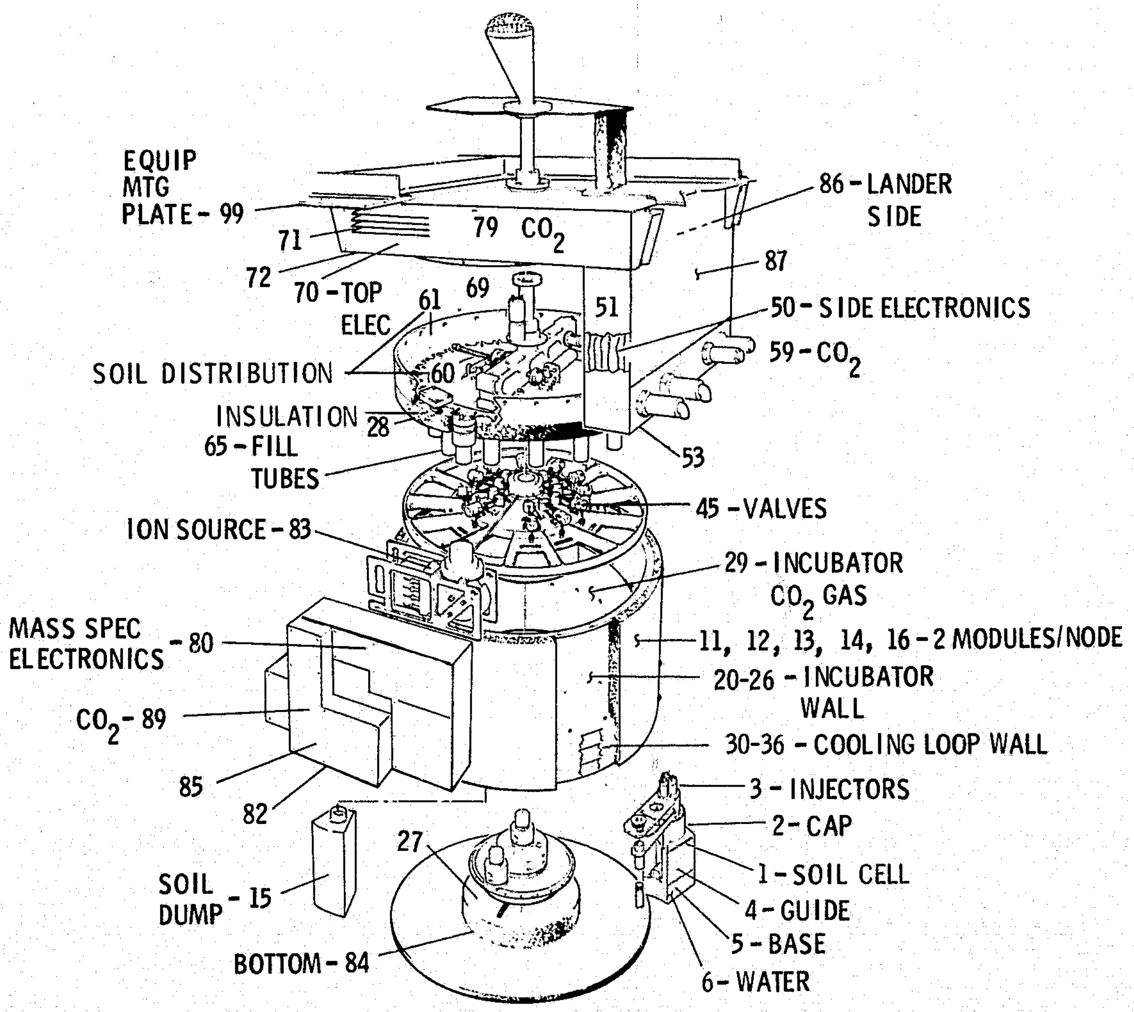
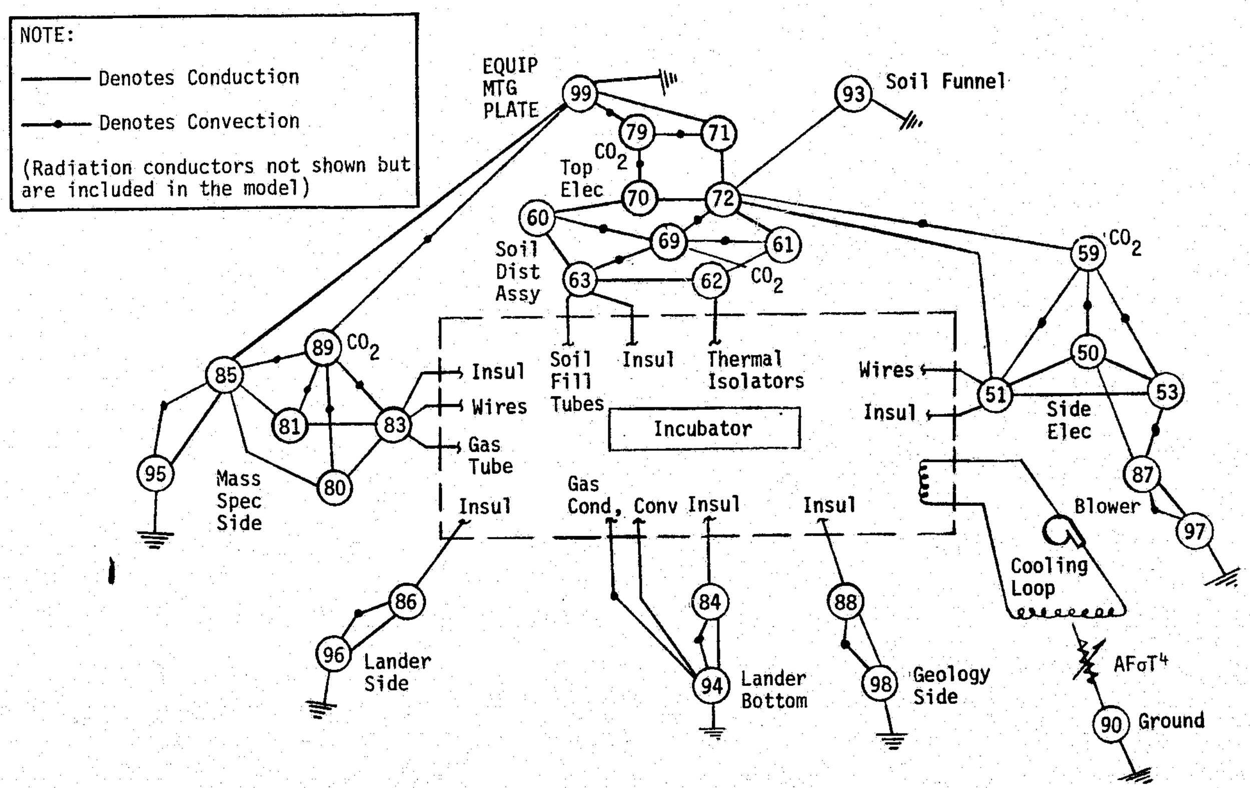


Fig. II-5 Instrument Thermal Node Locations

The full 71-node model used the various lander interior environments as input parameters as shown in Figure II-6. Once this model had been used to calculate the thermal environment of the incubator module only, these results were used as input parameters for a 53-node model of the incubator alone which is illustrated in Figure II-7.



Thermal Network for Full 71-Node Thermal Model Showing Lander Thermal Interfaces

Subsequent calculations were made with the 53-node model to provide results with significantly less computer time without sacrificing appreciable accuracy.

Separate computer models were constructed for the cooling loop and for the nutrient injector. The cooling loop model was based on a 3-turn heat exchanger coil surrounding the incubator and a radiator coil on the outside of the lander. This model used the radiation/convection power series technique discussed in the November 1974 contract report. The nutrient injector model consisted of a 9-node network constructed specifically for the injector.

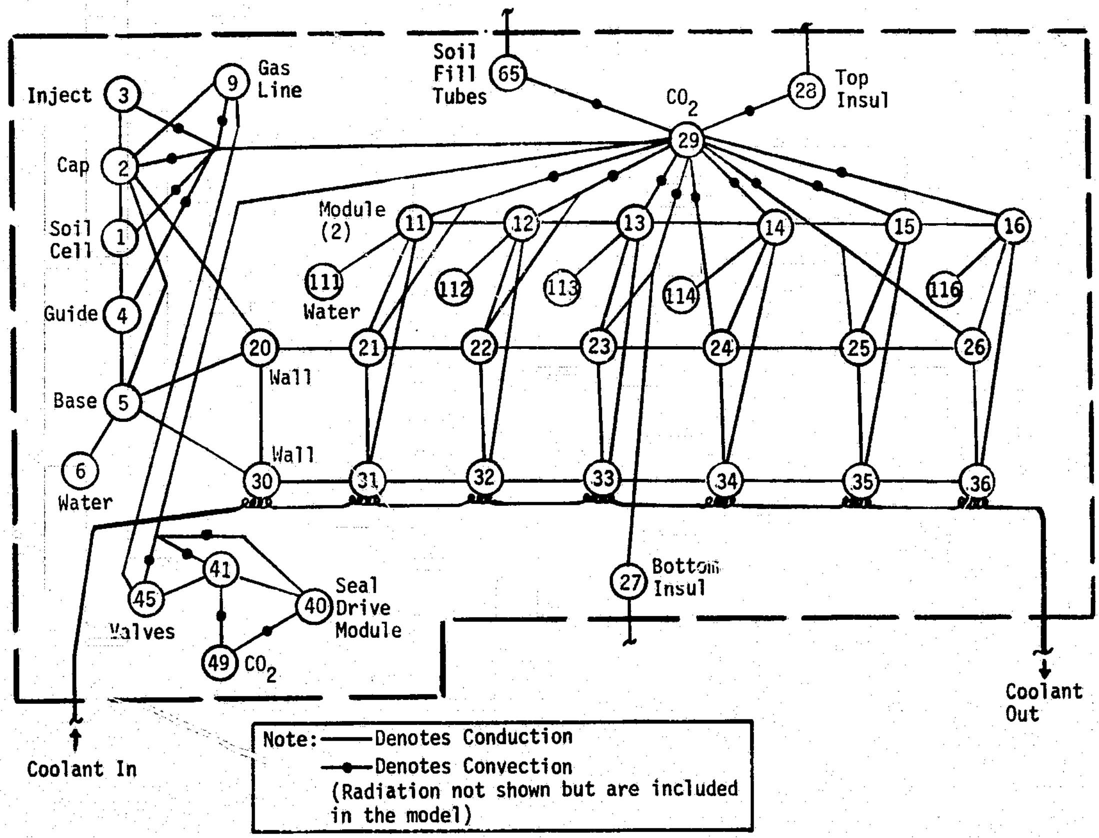


Fig. II-7
Thermal Network for 53-Node Thermal Model of the Incubator Showing Thermal Interfaces with the Remainder of the Unified System

These models were used to generate all the data discussed below.

B. COMPUTER MODEL RESULTS

1. Steady-State Incubator Heat Loads

To obtain an estimate of the mass of water required to keep the incubator cool during the day, the 71-node model was used to calculate the steady state heat loads at half hour intervals throughout a Martian day and night. These steady-state calculations did not consider the transient effects of thermal capacities since the quantity of water was not yet available.

The results of these calculations, as shown in Figure II-8 were used to estimate the amount of water required to maintain the incubation temperature. The heat loads were calculated for two different possible materials (aluminum or titanium) used for

fabricating the soil distribution assembly (SDA). Since the SDA is located between the incubator and the electronics, it is a conductive path. The lower thermal conductivity of titanium is significant in reducing the heat leakage into the incubator, resulting in a smaller mass of water required. The mass of water is calculated from the area under the part of the heat load curve during which the outside temperature is too warm to obtain cooling with the coolant loop.

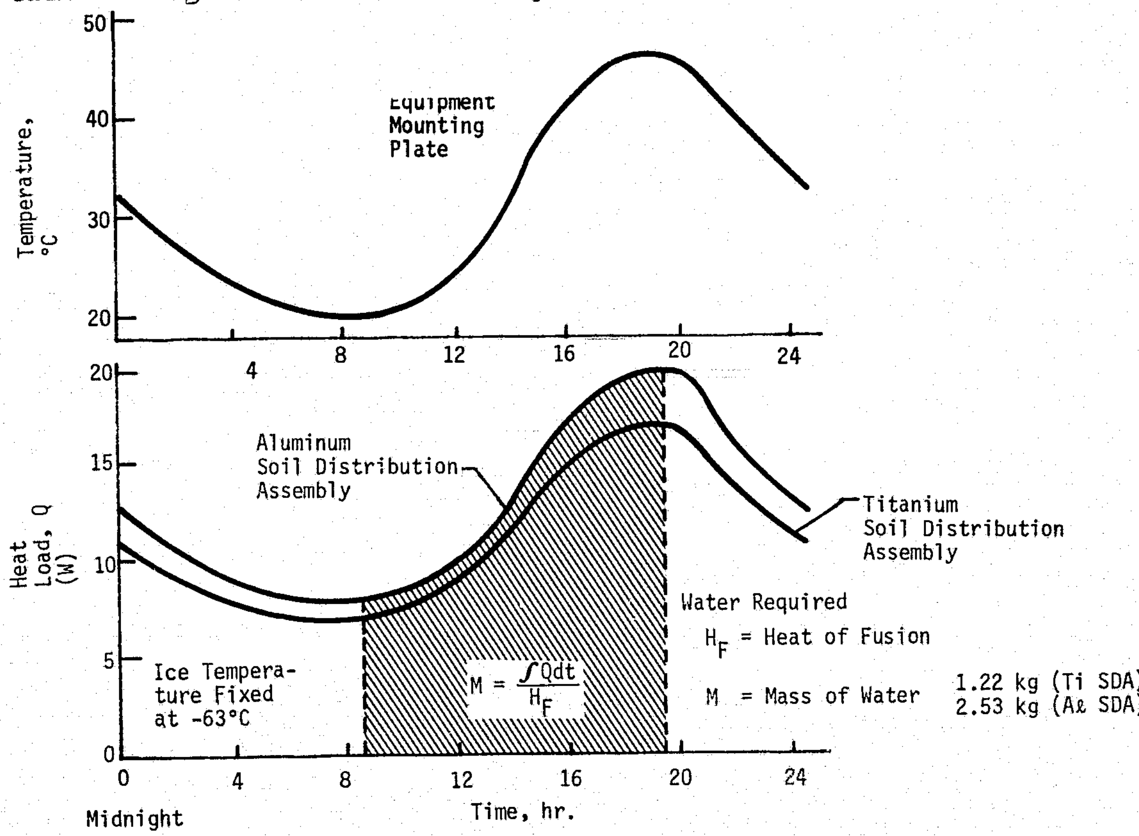


Fig. II-8
Determination of Mass of Water Required from Steady State Heat Load Calculations

2. <u>Transient Incubation Temperatures and Loads</u>

Using the calculated water mass as an input, the 71-node model then calculated the heat loads and temperatures on a transient basis taking into account all the heat capacities in the system. This result, shown in Figure II-9, shows that the transient heat loads are somewhat less than the steady-state approximation. Thus, another iteration on the mass of water required yielded 1.20 kg for the titanium SDA and 1.38 kg for the aluminum SDA. The calculations are somewhat conservative because the time shown for dependence on the ice (8:30 to 19:30 = 11 hrs) is longer than the time when the external temperature is less than 0°C and is thus capable of removing heat through the cooling

loop. If this time is used (8:30 to 17:00 = 8:30 hrs), then the required water would be 1.00 kg and 1.15 kg for the titanium and aluminum SDAs respectively.

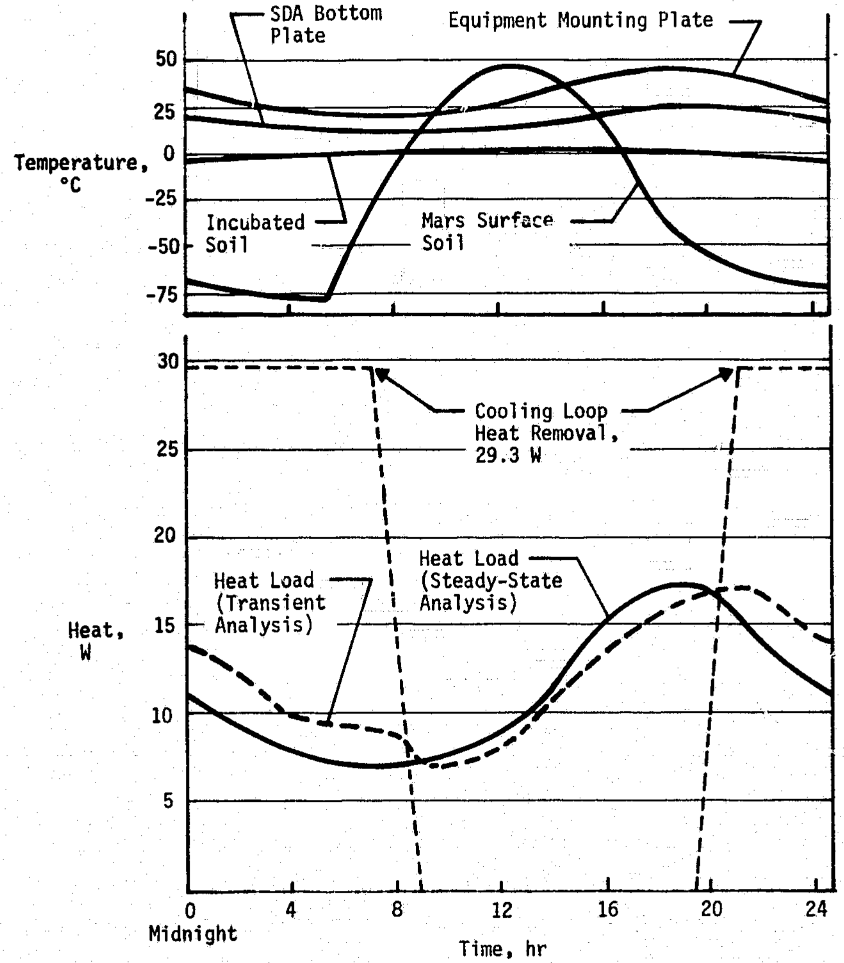


Fig. II-9
Transient Incubation Temperatures and Heat Loads (Hot Case) with Ti SDA, 1.33 kg Water on 10 W Dissipation and Electronics and Mass Spectrometer

The heat required to be removed by the cooling loop is shown for the periods that it operates. These curves are derived by integrating the total area under the transient heat load and allowing a 36% margin in heat removal by the cooling loop to allow for heating of individual test cells. The total integrated heat load is 970 kJ while the integrated cooling loop heat removal required is 1320 kJ. The latter value defines the 29.3 W continuous heat removal rate indicated in Figure II-9 and is thus used below to size the cooling loop radiator and blower power.

3. Ice Melting Calculations

The 53-node thermal model for the incubator was employed to calculate the transient effects on the melting of the ice in specific module water jackets. Each pair of adjacent modules in the Unified System was treated as a separate thermal node for these calculations as illustrated in Figure II-10.

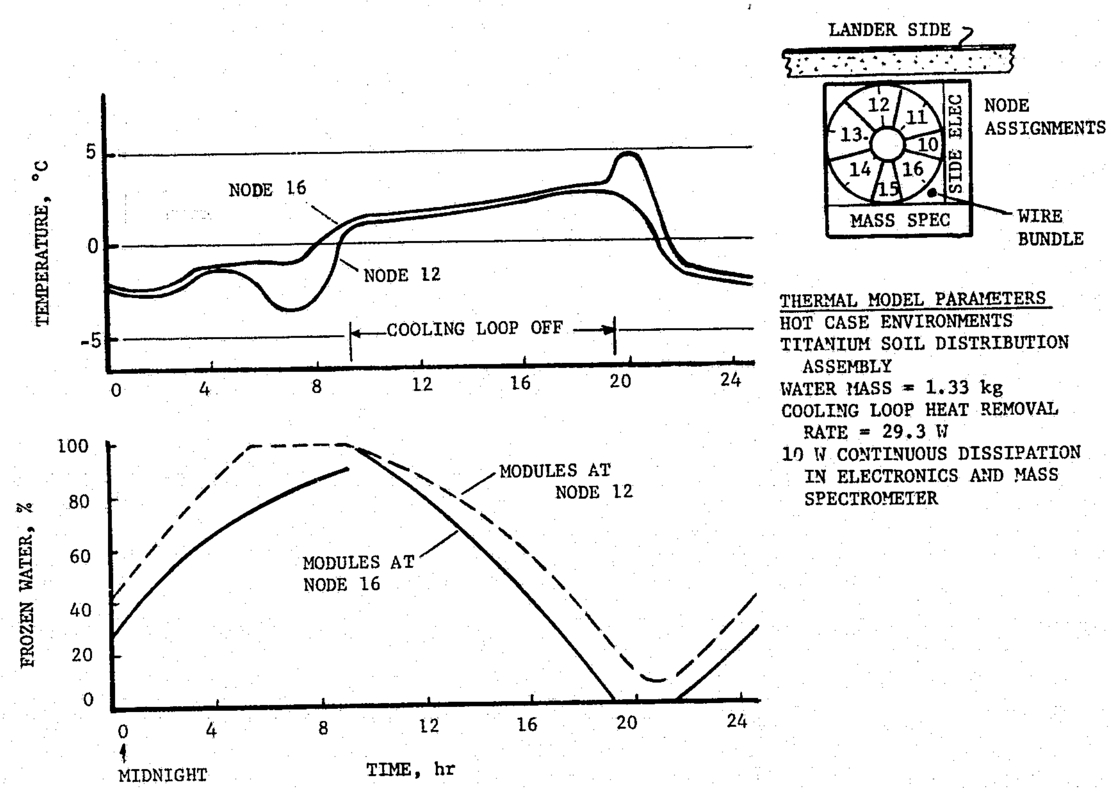


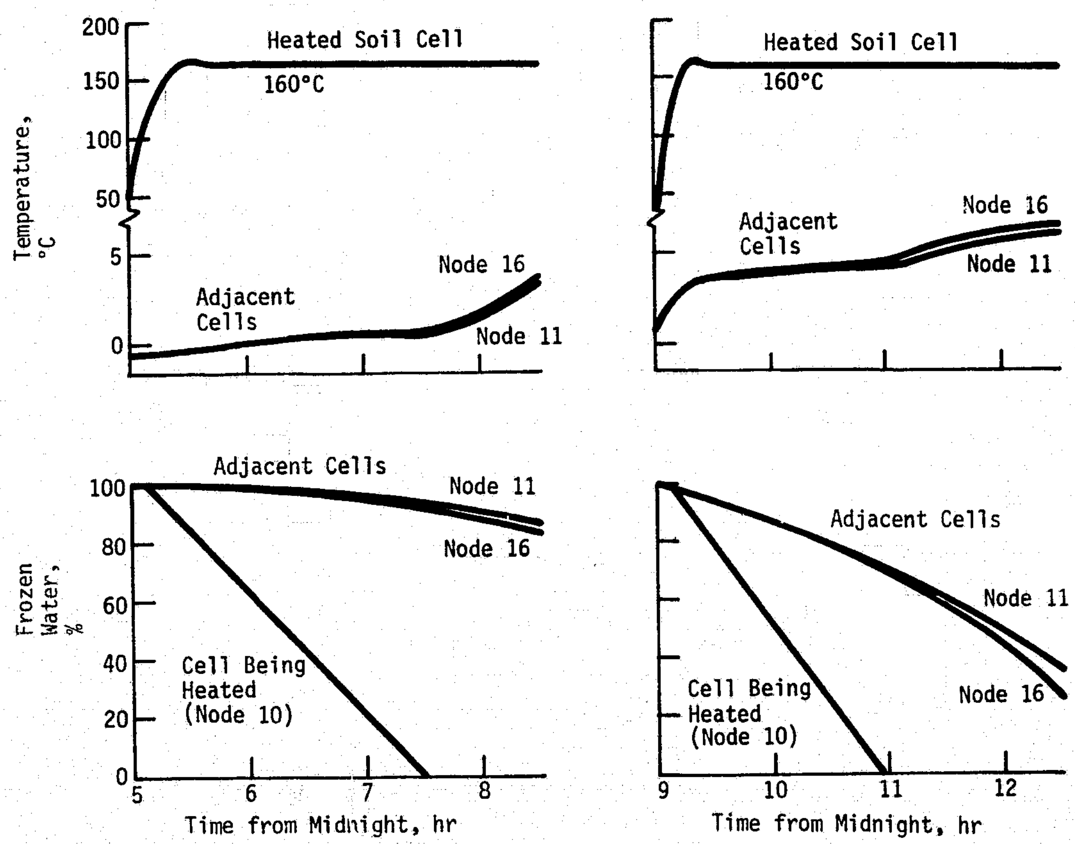
Figure II-10 Melting Curves for 2 Module Locations (Hot Case)

The curves show the temperature excursions of the test cell modules which can be seen to remain well below the specification maximum of 20°C even for the hot case.

These thermal models provide a powerful means of evolving design iterations to ensure overall performance within specifications. An example of this use is illustrated in these calculations of the melting curves. The model was built with the bulk of the wires routed in the corner where the electronics module and the mass spectrometer module surround the incubator. The melting curve calculations demonstrated that for the test cell modules in that corner (node 16), not quite all the water would refreeze in the hot case diurnal cycle and that gradually these modules' temperature would rise above specification. Thus, the thermal

model calculations demonstrated the need to reroute these wires through an open corner rather than this closed corner. The calculations also showed that for the modules at node 12 the refreezing was quite adequate.

The next step in the calculations involved determining the melting rate when a test cell is being heated to 160°C for three hours (control sterilization). For this case, node 10, which consists of one test cell module instead of two was identified as the heated module. The temperature and percentage of water melted for this node and for the two adjacent nodes (11 and 16) were calculated. The results are shown in Figure II-11 with the node locations illustrated in Figure II-10.



Temperatures and Melting Curves for 160°C Sterilization (Hot Case) for the Cooling Loop Both On and Off. Model Parameters Include 121 g Water per Module, Cooling Loop Heat Rejection Rate = 29.3 W, Titanium SDA, and 160°C Sterilization Heater Power = 14 W

These curves show that, during the 3-hour sterilization heating, the adjacent nodes still have more than 40% of the water frozen even when heated at a time during the Martian day when the cooling loop is not operating. The adjacent cell temperatures stay well below the 20°C maximum.

4. Soil Heating

There is a large variety of possible soil heating programs in addition to the control sterilization for which the melting curves were calculated and discussed in Section II-b.3. Radmer identified one program as a method of determining what fraction of evolved gas in a biology experiment comes from biological reactions compared to that from chemical reactions. This involves heating two cells to temperatures of 90°C and 70°C respectively. The soil reaches that temperature uniformly throughout the cell in a short time and stays there for 24 hours.

Initial calculations showed that this objective could not be met for a test cell with only an external heater. This result led to including a central heater in the test cell design as discussed in Section II-A-1. The results of subsequent calculations with the central heater included are given in Figure II-12.

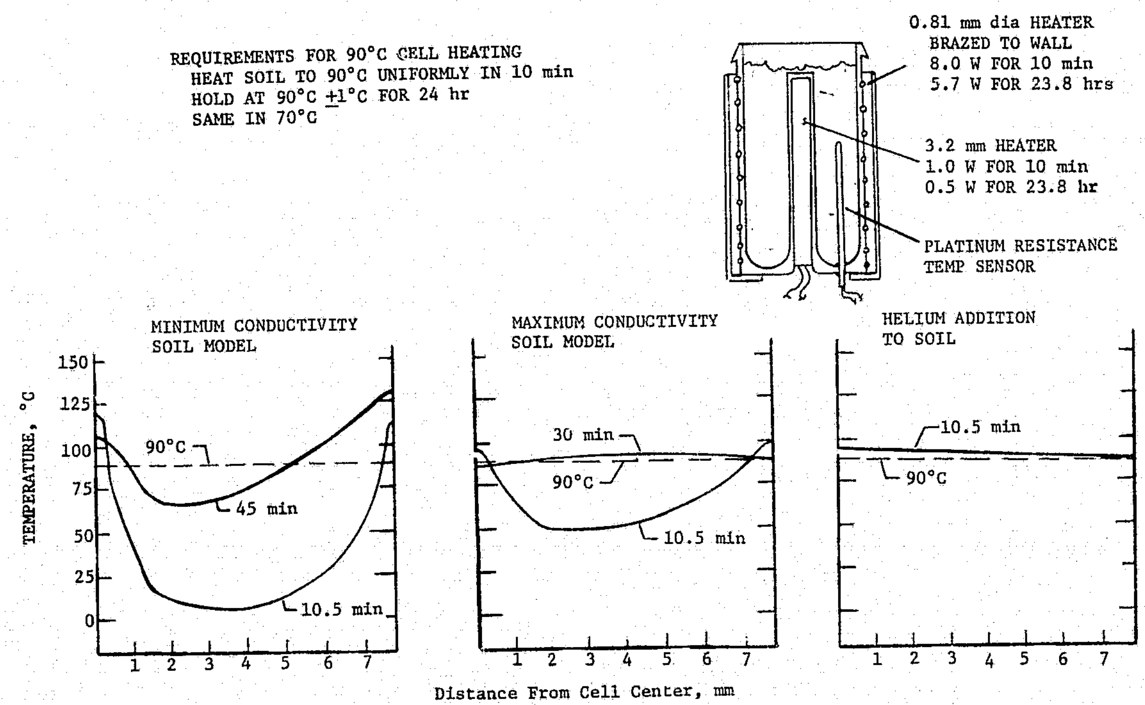


Fig. II-12 70°C/90°C Controlled Soil Heating

The calculations show that the central heater improves things considerably. The goal of achieving $\pm$ 1°C uniformity in the soil temperature within 10 min still cannot be done if the soil corresponds to the minimum thermal conductivity Mars soil model and even for the maximum conductivity model, uniformity is not achieved until 30 min. Adding Helium to the soil increases its conductivity sufficiently to achieve this goal. An alternate approach would be to add thermal conduction vanes in the test cell. These calculations provided design information which could be used for improving the thermal design of the cells and illustrate the potential use of this and the other computer thermal models generated for the Unified System.

5. Injector Heating

The 9-node computer thermal model of the nutrient/reagent injector was used to calculate several nodes of operation of the actuation heaters in the injectors. Using the boundary conditions established by the incubator thermal model, the program calculated steady-state temperature as a function of heater power for the heater, the Sn/Sb fusible spacer, the housing, and the fluid in the capsule. These calculations were performed with the test cell cap temperature held at 0°C and at 160°C.

The 0°C calculations were used to determine the capability of this injector heater to preheat the fluid in the capsule enough to provide adequate expulsion vapor pressure. The results seen in Figure II-13 show that, with 1.5 W into the heater, the fluid can achieve a temperature of 38°C resulting in an expulsion vapor pressure of 50 torr (6.7×10^3 Pa) or with 2.0 W, 50°C resulting in 92 torr (1.23×10^4 Pa).

The calculations with the cap at 160°C were performed to determine the feasibility of using the injector heater to keep the injector housing at the same sterilization temperature as the cap and test cell so that it too can be sterilized. The results demonstrate that in this circumstance the power should be kept below 1.5 W to avoid melting the spacer. Consequently, the housing temperature will not go higher than 150°C. If the injector has already been actuated, this limitation does not apply and 2.5 W will heat it to 160°C. The capsules have not yet been tested to see if they can withstand the 160°C vapor pressure of 4636 torr (6.18×10^6 Pa) without rupturing. Thus, the question of being able to sterilize the housing without melting the spacer may be irrelevant since it might be required that a sterilization be performed only after the injectors have been actuated.

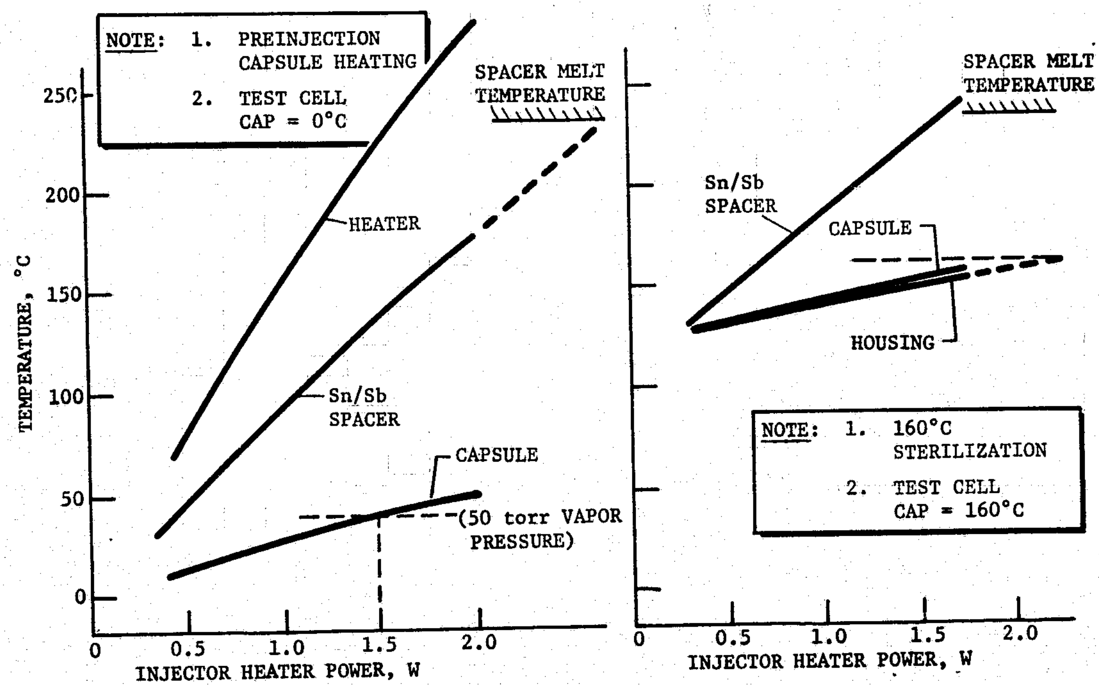


Fig. II-13
Heating Curves for the Nutrient/Reagent Injectors for Preinjection Capsule Heating and for 160°C Sterilization

6. Cooling Loop

Assuming that the radiator on the outside of the lander is constructed simply from a coil of tubing, the heat rejection rate of the radiator as a function of tubing length was calculated for several mass flow rates and tubing diameters. Results for standard tubing sizes, 1/2 in. (1.27 cm) and 3/4 in. (1.81 cm) are shown in Figure II-14 for nitrogen mass flow rates of 4.5 and 6.8 kg/hr. For the system requirement of 29.3 kg/hr derived above (Section II-B.2) the tubing lengths range from 5.6 to 7.9 meters.

The same type calculations were then repeated with the mass of aluminum radiator tubing treated as parameter instead of the length. Typical data from these calculations are shown in Figure II-15 where the radiator mass is shown as a function of nitrogen mass flow for three tubing sizes and three heat rejection rates including the system design value of 29.3 W.

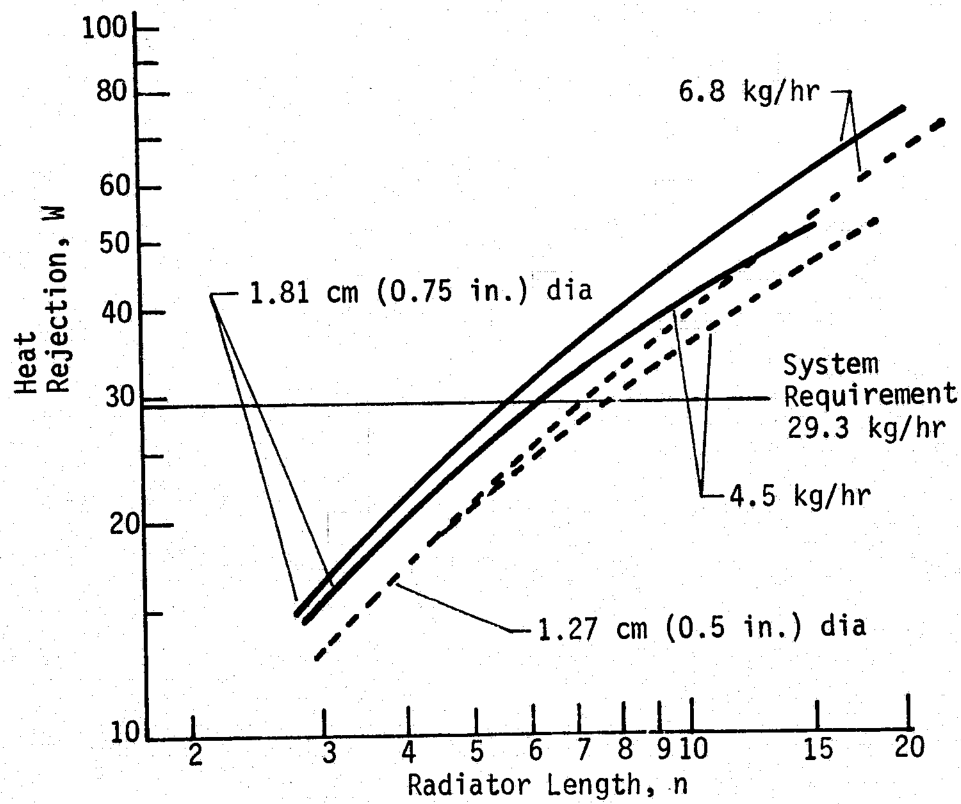


Fig. II-14 Radiator Lengths Required for Heat Rejection

The resultant curves shown in Figure II-15 demonstrate that a significant reduction in radiator mass is achieved by using 1/2 in. (1.27 cm) tubing rather than 3/4 in. (1.91 cm) but not much reduction in going to 0.79 cm tubing.

Furthermore, the results demonstrate that the mass of radiator can be reduced by increasing the nitrogen mass flow rate up to about 5 kg/hr but not much beyond that. There is very little weight saving achieved by decreasing the tube size or increasing the mass flow further than 1.27 cm and 5 kg/hr, respectively. Since going further in both of these parameters also increases the blower power required, these two values were chosen as optimal. Thus, the design point uses a radiator mass of 0.44 kg with length of 7.8 meters.

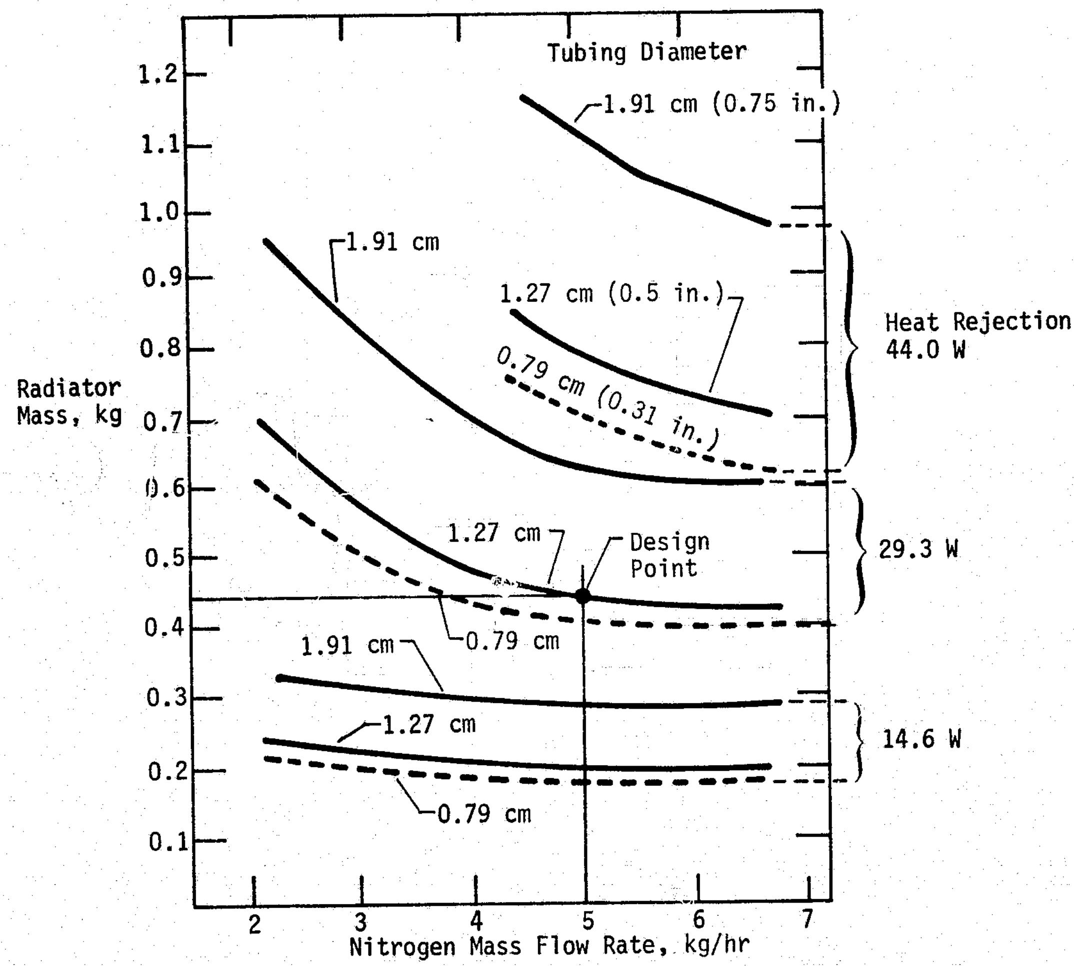


Fig. II-15 Radiator Mass Required as a Function of Coolant Mass Flow Rate

7. <u>Cold Case Incubator Heating</u>

Although most of the calculations were directed at the more difficult problem of the hot case environment, calculations were also made for the heat required to maintain 10°C in the incubator in the cold case environment shown in Figure II-3. These results were 11.9 W maximum at 7:30 and 7.7 W minimum at 18:00.

III. TEST CELL MODULE

The Modular design concept shown in the November 1974 contract report was implemented into detail designs and fabrication of a test cell module, the incubator structure, and a breadboard electronic system for thermal control of the module.

A. MECHANICAL DESIGN AND FABRICATION

The major impact of the modular design configuration study on the USMLD was the development of the concept of a plug-in module for each test cell. The basic functional elements of this module are the same ones developed and tested during the previous phases of this program, except that they are assembled into a removable module rather than being mounted separately on a common platform. These elements include a test cell that sits under the soil fill tube until it has been loaded with soil. This test cell is then translated and lifted to a sealed position by the action of the seal drive plunger on the translation and lifting mechanism. It also includes the gold gasket seal between the test cell and its stationary cap. The cap contains up to three injectors for releasing the preselected nutrients, reagents, and/or gases into the test cell. It also contains the gas line to the gas sampling valve. This connection is made through a vacuum fitting that is disconnected when the module is removed.

A new addition to the module, resulting from the revised thermal design, is the sealed container of water/ice. It acts as a heat capacitor to maintain incubation temperatures during the portion of the Martian day when the external temperature seen by the radiator is too high. This water is frozen by the cooling loop during the Martian night. The heat exchanger of the incubator is in good thermal contact with this water/ice container. Figure III-1 shows an artists concept of the module. Figure III-2 gives a cross section view of the mechanical functioning parts with the module in place in the incubator under the soil distribution assembly.

1. Water Jacket Test Cell Carrier

The water jacket served as the principle structure for the module in the water jacket design approach. With the volume constraints imposed by the overall height and width dimensions allocated to the Unified System (to fit as a replacement for the Viking '75

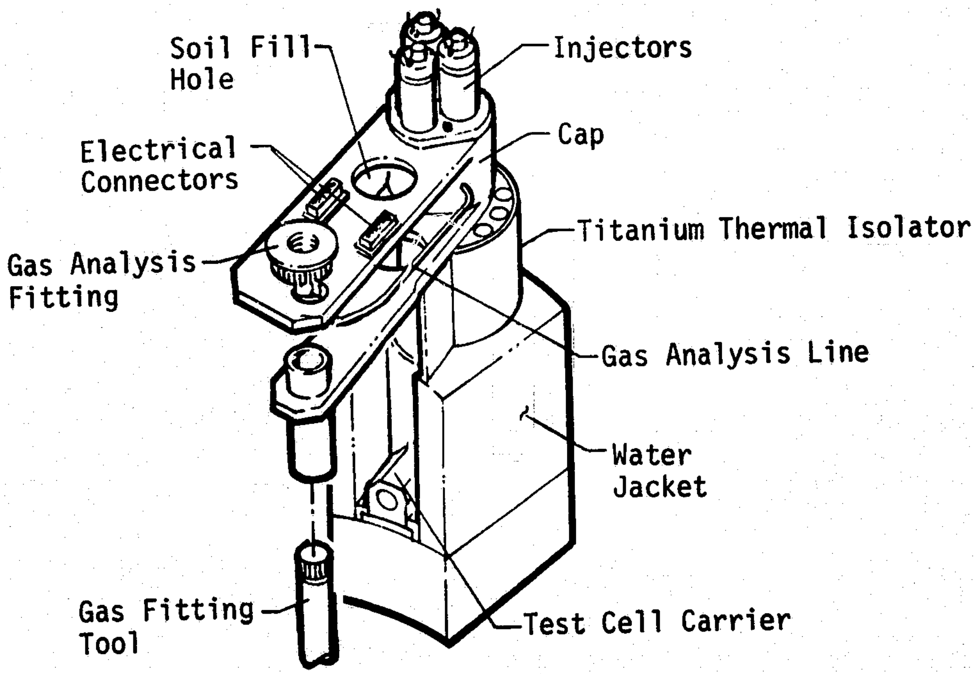


Fig. III-1 Test Cell Module

biology instrument in the lander), the possible volume allocated for water was short of the 121 cm^3 design goal. The resultant volume of 90 cm^3 is consistent with the least conservative figure of 1.00 kg determined for the required mass of water in section II-B.2. (1.00 kg/11 test cells = 90.9 g = 90.9 cm^3). The volume could be increased to 121 cm^3 by increasing the height by 4.1 mm. This height increase could probably be achieved by reducing the allocation for the top electronics (packaging design for the electronics has not yet been done) by the same amount.

The water jacket was fabricated by hogging out a single block of aluminum leaving a hollow container with reinforcing webs in the interior to provide structural integrity for the 35 psi (2.41×10^5 Pa) vapor pressure during 125°C heat soak. An expansion absorber was installed at the center of each of the 18 cells formed by the reinforcing webs in order to eliminate danger of rupture of the sealed container during freezing. The expansion absorbers are made of closed pore silicone foam which can absorb a compression of 50%. This foam is capable of withstanding extended exposure to temperatures higher than 200°C. The container was then sealed by heliarc welding. Two fill holes were left in the bottom for addition of the water. Top and bottom views of this water jacket before welding the cover plates are shown in Figure III-3. The expansion ab-

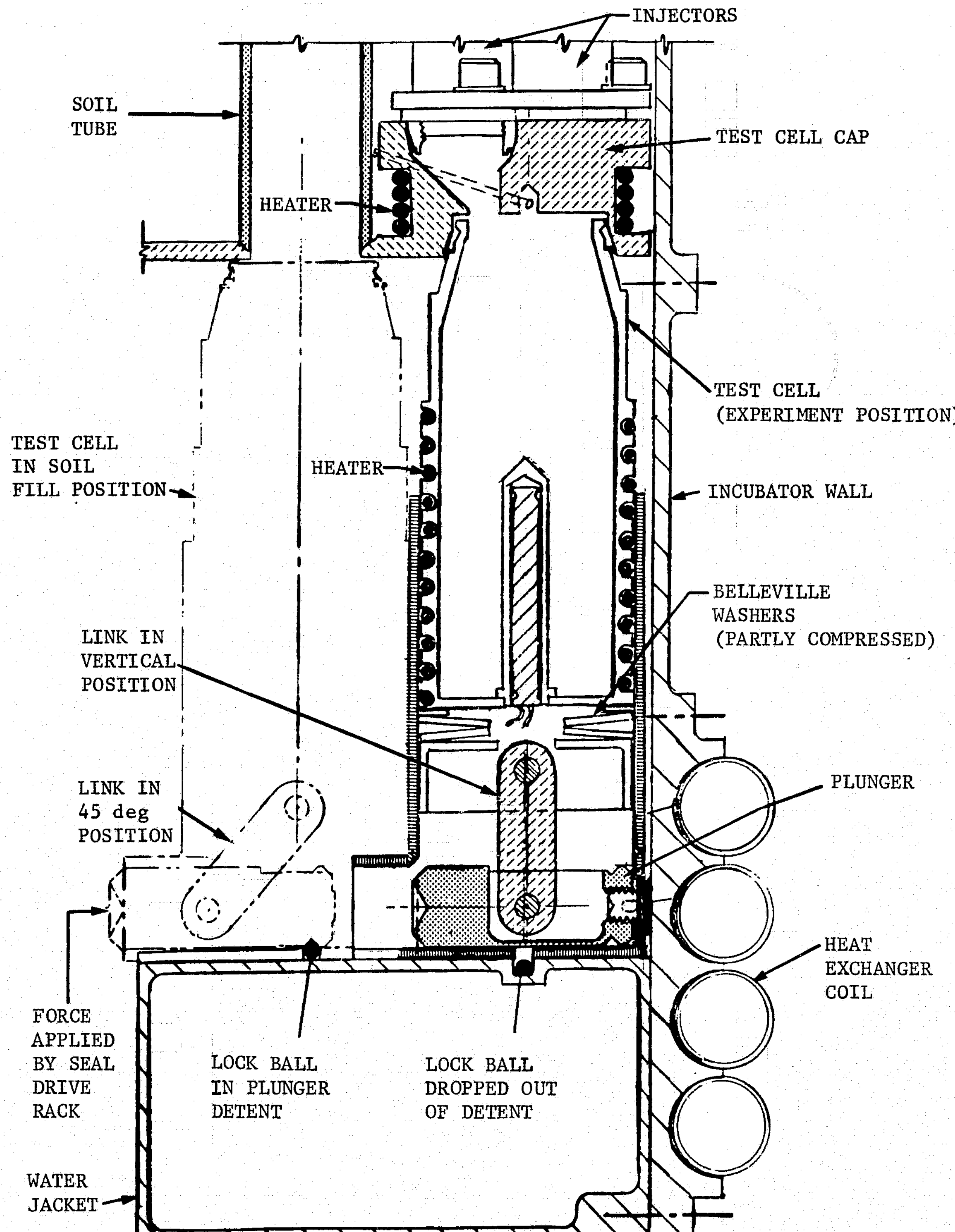
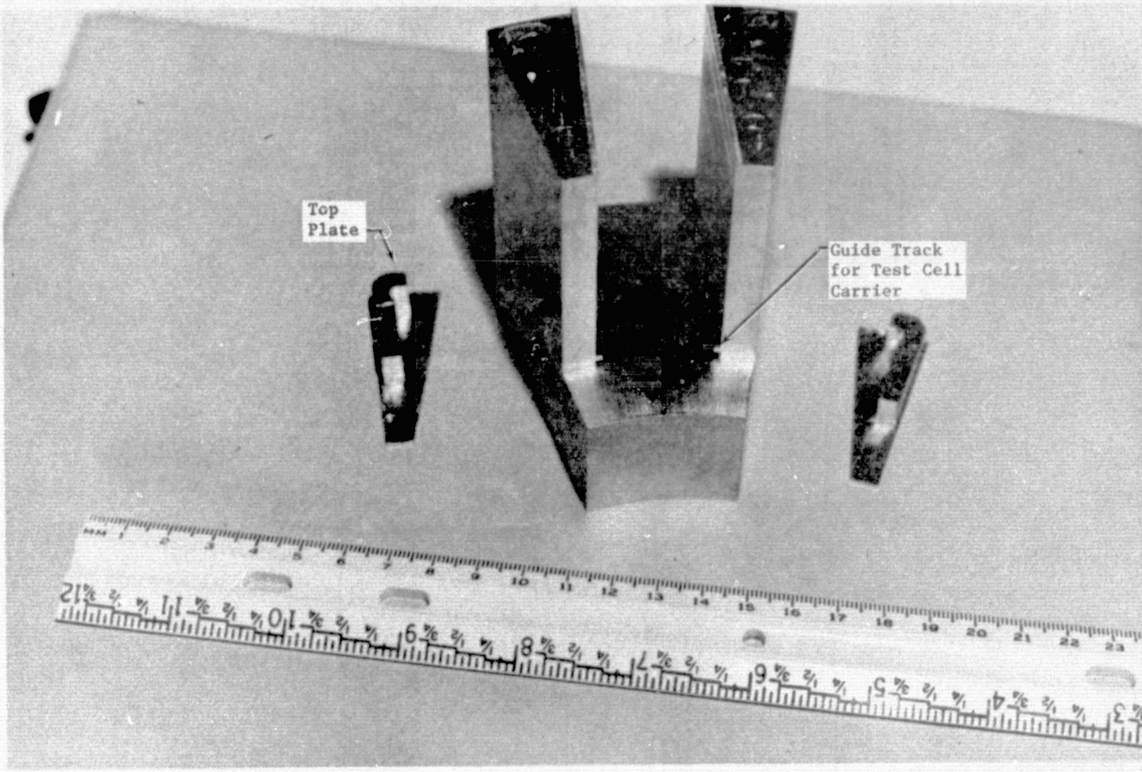
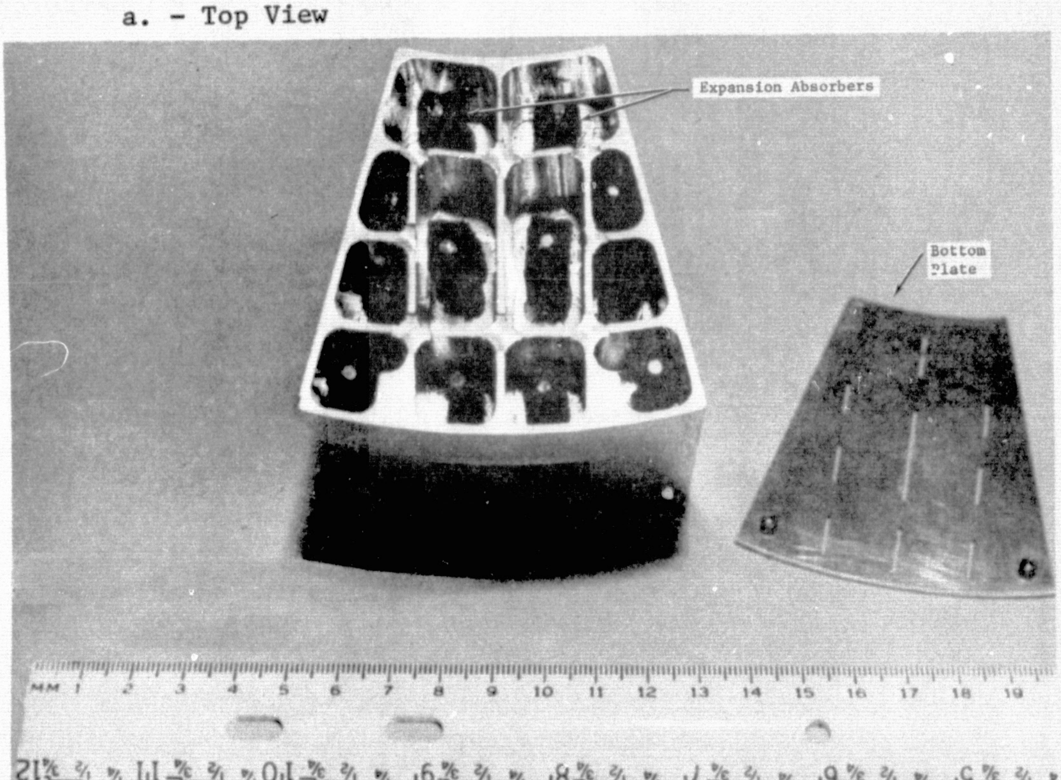


Fig. III-2 Cross Sectional View of Test Cell Module Functioning Parts Shown in Place in the Incubator



a. - Top View



b. - Bottom View

Fig. III-3
Water Jacket for Test Cell Module before Welding Top and Bottom Plates

sorbers can be seen in views a and b. They were mounted centrally on thin mounting rods in each cell. The guide track for the test cell carrier is machined directly into the jacket. The total mass of the water jacket complete with 90 g of water is 310 g.

The temperature sensor installed in the base of the water jacket is a platinum resistance, model number EL 100-A-500-F12-E-WN-2, from Hy-Cal Engineering of Santa Fe Springs, California. It has a resistance of 500 ohms at $0^{o}C$.

2. Test Cell and Cap

The test cell is designed with an interior volume of $10cm^3$ so that it can be loaded with up to 8 cm^3 of soil even at the maximum lander tilt angle. A cross section view of the test cell is shown in Figure III-4, illustrating the central heater and the brazed heater on the outer surface. The guides shown here insure that the test cell slides up smoothly in its carrier during the sealing operation. The external temperature sensor is the one used by the temperature controller circuit while the internal one is installed for test monitoring purposes during the development program.

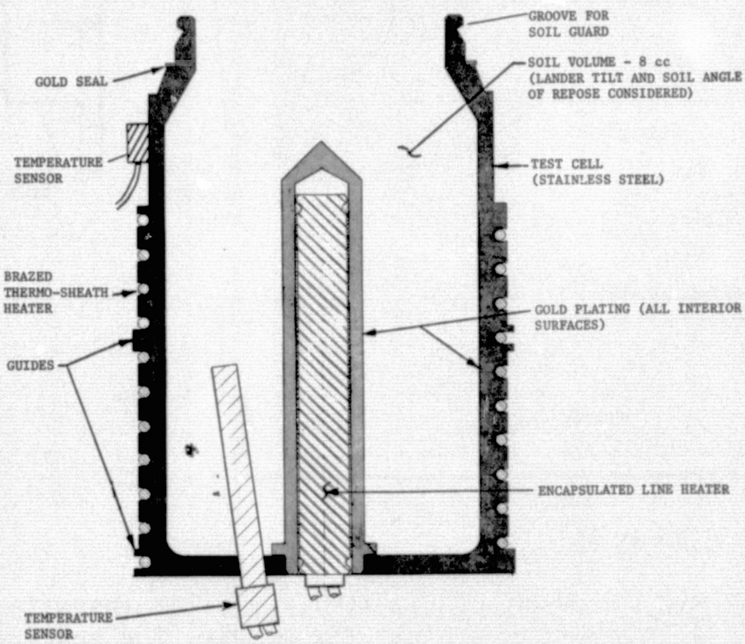


Fig. III-4 Test Cell Configuration

A schematic diagram of the cap receiving the test cell in the sealed position is shown in Figure III-5. This cap includes the framework that supports the gas sampling connector and the electrical connectors. It includes a hole to receive the soil fill tube from the soil distribution system. The three injectors are mounted into this cap and clamped down by a retainer plate. The cap is attached to the top of the water jacket by a titanium isolator which allows some thermal isolation of the cap and cell from the water jacket for sterilization heating without melting the ice too fast. The injector fluid openings are designed for a wide-open direct path for the fluid from the injector capsule to the soil in the test cell.

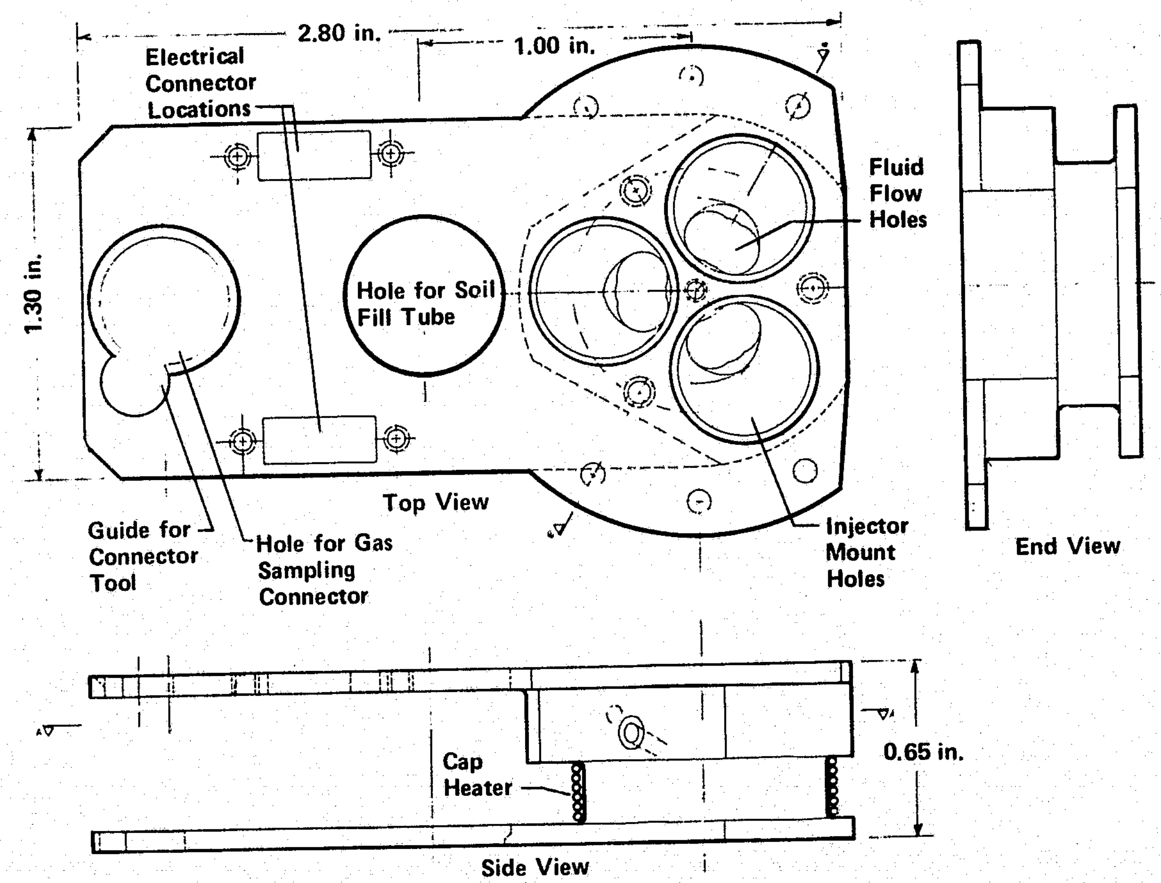
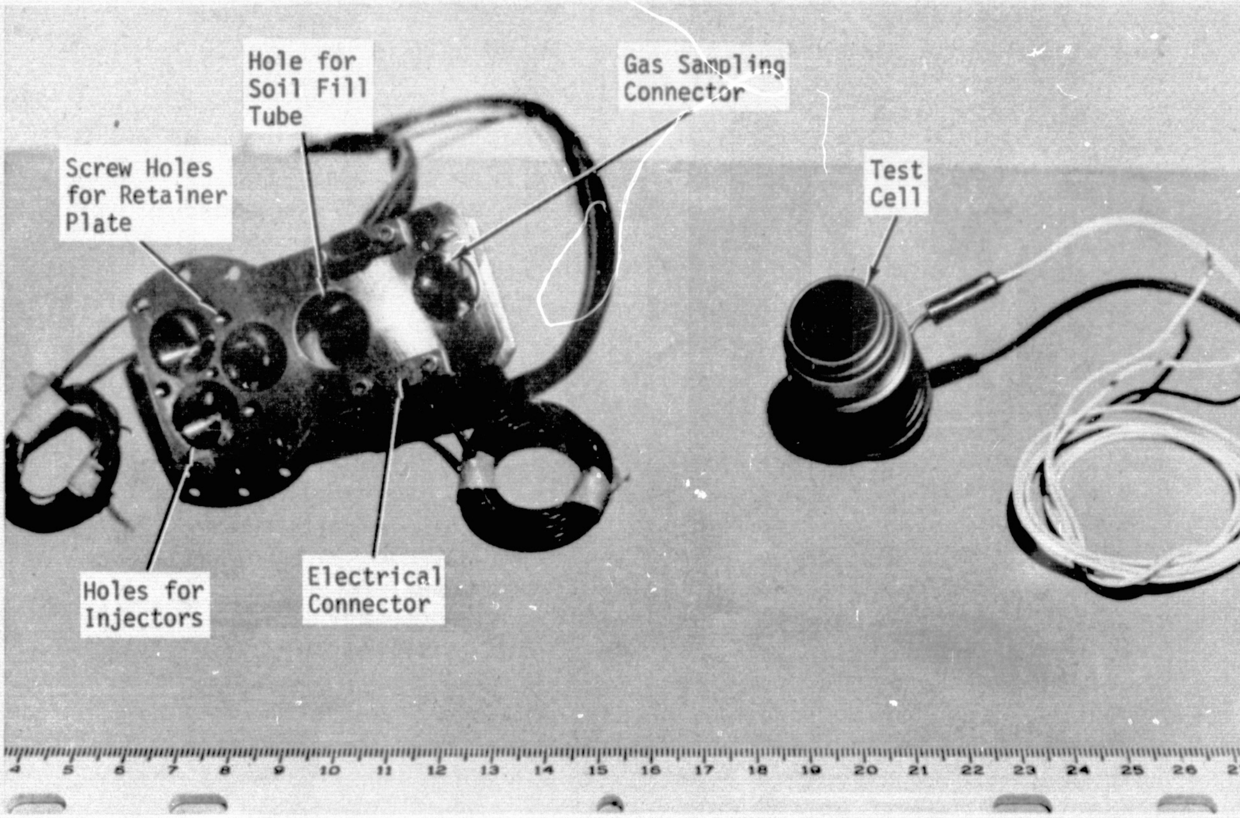
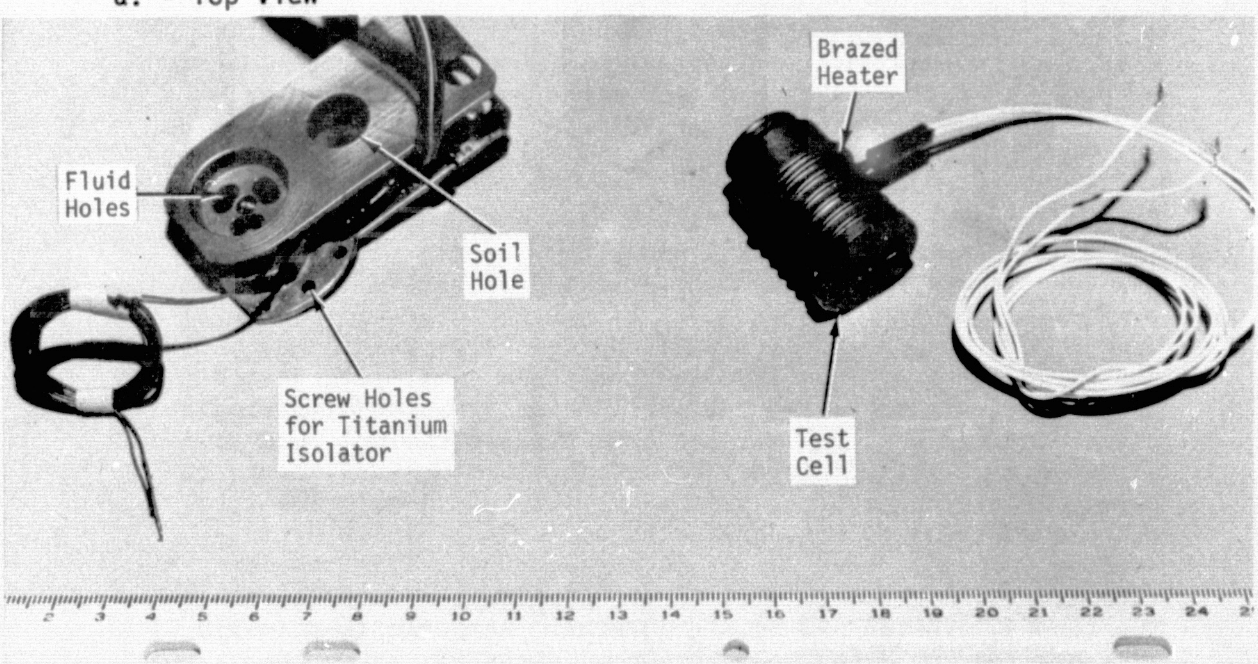


Figure III-5 Cap Schematic

The test cell and cap are shown in Figure III-6 after installation of the heaters before assembly into the module. The heaters on the outside of the cap and of the test cells are 0.032 in. (0.81 mm) diameter sheathed conductor NiV heaters each having a resistance of 17.2 ohms for nominal operation at 33 W. They are Thermo-Sheath elements from Thermo-Couple Products Co. of Winfield, Illinois and were assembled and brazed to the cell and cap by Tayco Engineering, Inc., of Long Beach, California.



a. - Top View



b. - Bottom View

Fig. III-6 Cap and Test Cell

The gas line heater, also installed by Tayco, is a Kapton encapsulated spiral wrap 28 gauge heater wire with a resistance of 146.9 ohms for operation at 4 W.

The line heater mounted in the central inversion of the test cell is a 2 W (288 ohm) cartridge heater from Hot Watt, Inc. with a diameter of 0.125 in. (3.18 mm). The temperature sensors bonded to the cap and to the test cell for temperature control operation are Rosemont model 118 MF500A platinum resistance thermometers with a resistance of 500 ohms at $0^{o}C$ and a slope of 1.956 ohms/^{o}C.

3. Nutrient/Reagent Injector

Following the injector performance tests during the previous contract phase, several design modifications for improvement of performance, capacity, and manufacturability became apparent. These changes included increasing the fluid volume, developing the isolator diaphram, developing the techniques for large quantity production of the capsules, improvement of the heater bushing-connector assembly, addition of an actuation indicator, and enlargement of the fluid flow path. Figure III-7 shows the details of the injector design and an exploded view of the component parts along with a completely assembled injector. This injector represents a redesign to increase the volume of fluid from 0.36 cm^3 to 1.0 cm^3.

a. Isolator Diaphram - The original design for the isolator diaphram involved machining a thin diaphram into a small section of housing and then brazing this section between the upper and lower housing sections. This concept was changed to machine the diaphram directly in a single piece housing.

Evaluation and test of this manufacturing procedure has demonstrated that machining the diaphram directly into the housing leads to too high a probability of ending up with a weakened portion of the diaphram due to tool gouging. Therefore, two alternate diaphram manufacturing techniques were tested and evaluated. Both of them involved bonding a 1-mil gold plated stainless foil onto a shoulder in the inner wall of the single-piece housing. This foil is the same type as the one used repeatedly without failure for all the fluid delivery tests reported in the November 1974 final report MCR-74-421. The first technique used a gold/germanium eutectic (m.p. = $366^{o}C$) in a bonding procedure used in our microelectronics development laboratory for hermetic sealing of electronic circuit elements. The second involved use of a gold/nickel eutectic (m.p. = $950^{o}C$) in a brazing operation used in our advanced manufacturing facility laboratory for high strength brazing.

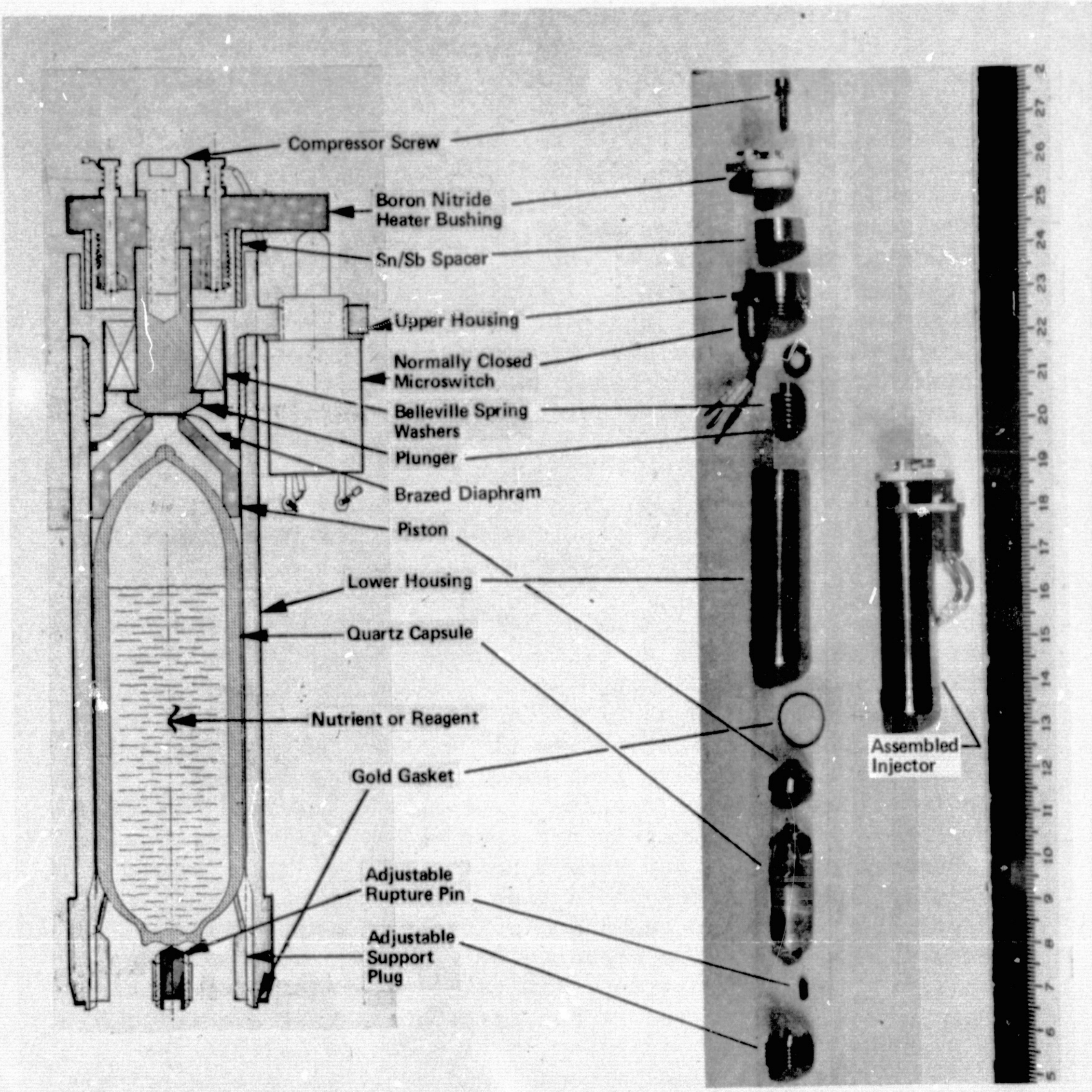


Fig. III-7 Injector Design Configuration, Component Parts and Assembled Unit

The injector housings were fabricated out of pure nickel to facilitate bonding the isolator diaphrams when using the first process. This bonding procedure was not successful, therefore, we switched very successfully to brazing with the Au-Ni eutectic, using the same nickel housings. The isolator diaphrams were brazed with 100% success on all three housings with the eutectic heated to a maximum of 1000°C with a 105 min rise time and a corresponding cooling period. The three diaphrams

were bonded using eutectic thicknesses of 2, 4, and 6 mils. All three resulted in completely leak-tight seals with the Helium leak detector. This demonstrated very little sensitivity to the eutectic thickness. The diaphrams were then deformed to give the bellows action and were leak checked again. The leak detector again showed complete seal integrity.

The Nickel housings turned out to distort easily, leading to difficulties in achieving a good seal when mounted with their gold gaskets into the test cell cap. Therefore, a set of three new housings were fabricated out of 303 stainless steel and 2 mil thick isolator diaphrams brazed as before. Again the brazing was 100% successful and the stainless provided a more reliable dimensional stability for achieving the seal at the test cell cap.

b. Quartz Capsule Development - The technique of making hand-made quartz capsules (used previously) resulted in a rather wide dimensional variation and thickness.

We worked out the fabrication of these capsules with an iterative tooling, fabrication and break test method resulting in a reproducible procedure. It involves mounting quartz tubing stock in a glass lathe, heating the closed end of the tubing, pressing while hot against a flat plate, then pushing the end out from the inside with a flat-ended tool. A 5 lb test gauge is pressed against the end to break the end if it is too thin. It is then immediately reformed while still on the lathe. A combined length gage and vacuum holder in the lathe chuck is used to hold the piece and define its length while thinning the loading restriction and cutting it off. Shape and size gages are then used for acceptance or rejection of the piece if it falls outside the tolerance limits of the injector mechanism. The procedure has resulted in quartz capsules that are certain to fit properly in the mechanism, will break to deliver the fluid with forces ranging between 5 and 30 lb and are relatively low in cost. A total of 100 such protocapsules were fabricated in two batches for use in the injector tests discussed below. Figure III-8 shows some of these capsules at three stages of use in the test program. On the left, are seen the protocapsules as they come off of the lathe, ready for loading with fluid. There are five capsules in the center which have been loaded with water by the methods described in the November 1974 Final Report MCR-74-421. L quid Nitrogen was used to freeze out the water while pumping out all the air (three cycles of freeze and thaw to outgas) and sealing the neck in the protocapsule with the oxy-acetylene torch. Each protocapsule was weighed before filling and then the two separated parts of the protocapsule were weighed after loading and sealing to determine the exact quantity of water loaded. The capsules on the

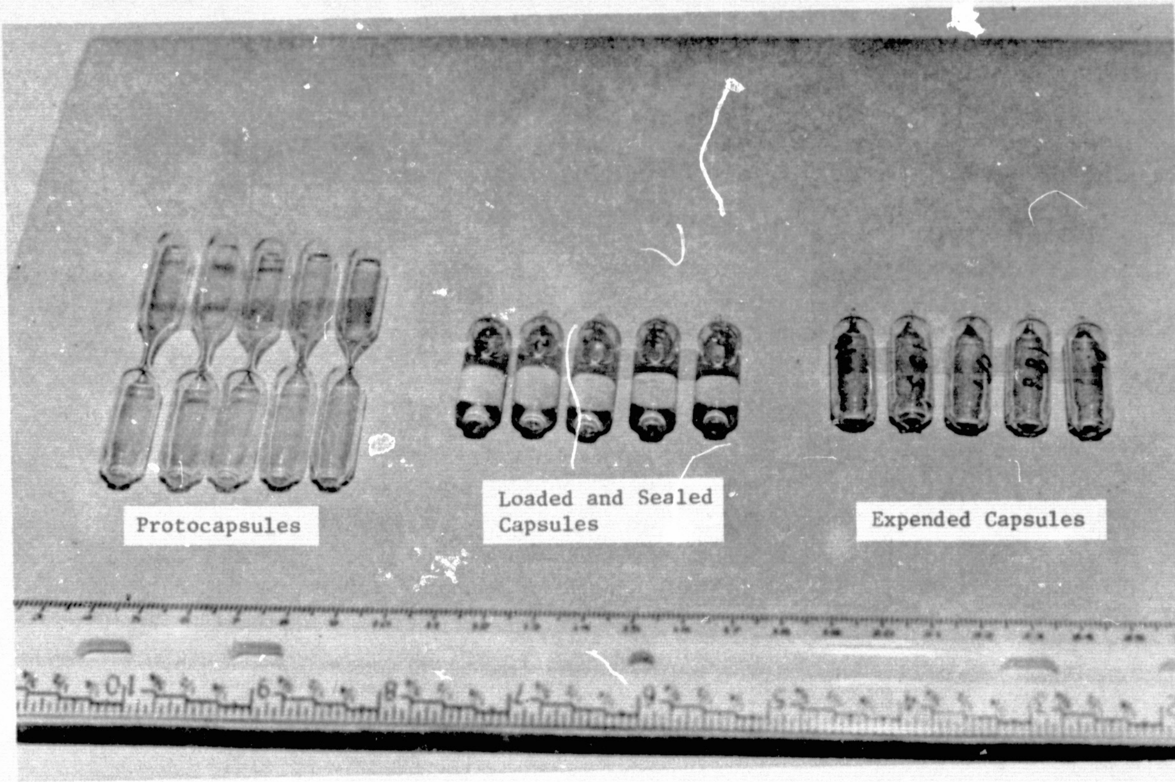


Fig. III-8 Quartz Injector Capsules

right (Figure III-8) are the result of being expended during the test program. The bottoms have been broken out by the rupture pin and the fluid expelled.

c. <u>Heater Development</u> - The original heater design consisted of a ceramic bushing wound with chromel wire and a separate connector board for attaching the external leads. The new design consisted primarily of building the heater bushing and electrical connector mount from a single piece of ceramic. These were first designed and built of Corning machinable glass ceramic.

The heaters were wound with 0.005 in. (0.127 mm) diameter chromel wire consisting of 7.5 turns for a total length of 8.75 in. (22.2 cm) and a total resistance of 12.7 ohms. The ends of the chromel wire were welded to brass terminal posts which were press fit into the ceramic coil form. The brass terminals were used for attaching the external wires. The welding technique was similar to that developed for welding the 0.005 in. chromel wire onto the mounting posts for the Viking entry temperature probe. They were thus welded using a capacitive discharge welder with a 1.0 joule energy pulse.

It was discovered that repeated operations of the injector heaters resulted in embrittlement breakage of the heater windings, even though it had been demonstrated previously that the chromel heater wire can be reheated many times without embrittlement. It was, therefore, presumed that this failure was due to amalgamation of the Sn/Sb fusible collar with the chromel heater during firing of the injector. The three injector heaters were, therefore, rewound and then coated with Sauereisen electric resistor cement No. 78 to protect the chromel from the melting Sn/Sb. This proved quite successful as demonstrated in subsequent tests.

The new design included mounting a normally closed microswitch on the injector upper housing in such a way that it would be opened by the motion of the ceramic bushing during actuation. When the Sn/Sb spacer melts, the expansion of the spring washers causes enough motion of the ceramic to push the switch actuator button. This plastic button tended to soften when an injector preheating procedure was attempted. This should be replaced with a switch having a ceramic actuator. After several firings, the glass ceramic heater bushings ended up cracking in half making them unusable for further tests. A new set of bushings were therefore fabricated out of a high grade boron nitride which eliminated this problem.

In addition, the connector pins were changed to bent pins with a 0.040 in. diameter end for plugging into a miniature jack. The other end was then mounted through a hole in the boron nitride and swaged in place. A hole drilled through the pin allowed threading the 5 mil diameter heater wire through the pin where it is spot welded to the pin at the top of the boron nitride bushing right at the right angle bend in the pin. This assembly provides a convenient test arrangement where the heater can be quickly removed from the housing by removing the miniature jacks before disassembly.

d. Fluid Path Enlargement - In order to ensure more reliable delivery of fluid from the injector capsule to the soil in the test cell, the capsule holder seen at the lower part of Figure III-7 was designed with inclined surfaces and maximum open path. The details of this design are shown in Figure III-9 which increases the fluid flow across the sectional area by a factor of three over the previous designs. The support fingers are used to hold the capsule away from the rupture pin until they are forced aside by the slant part of the capsule wall during actuation.

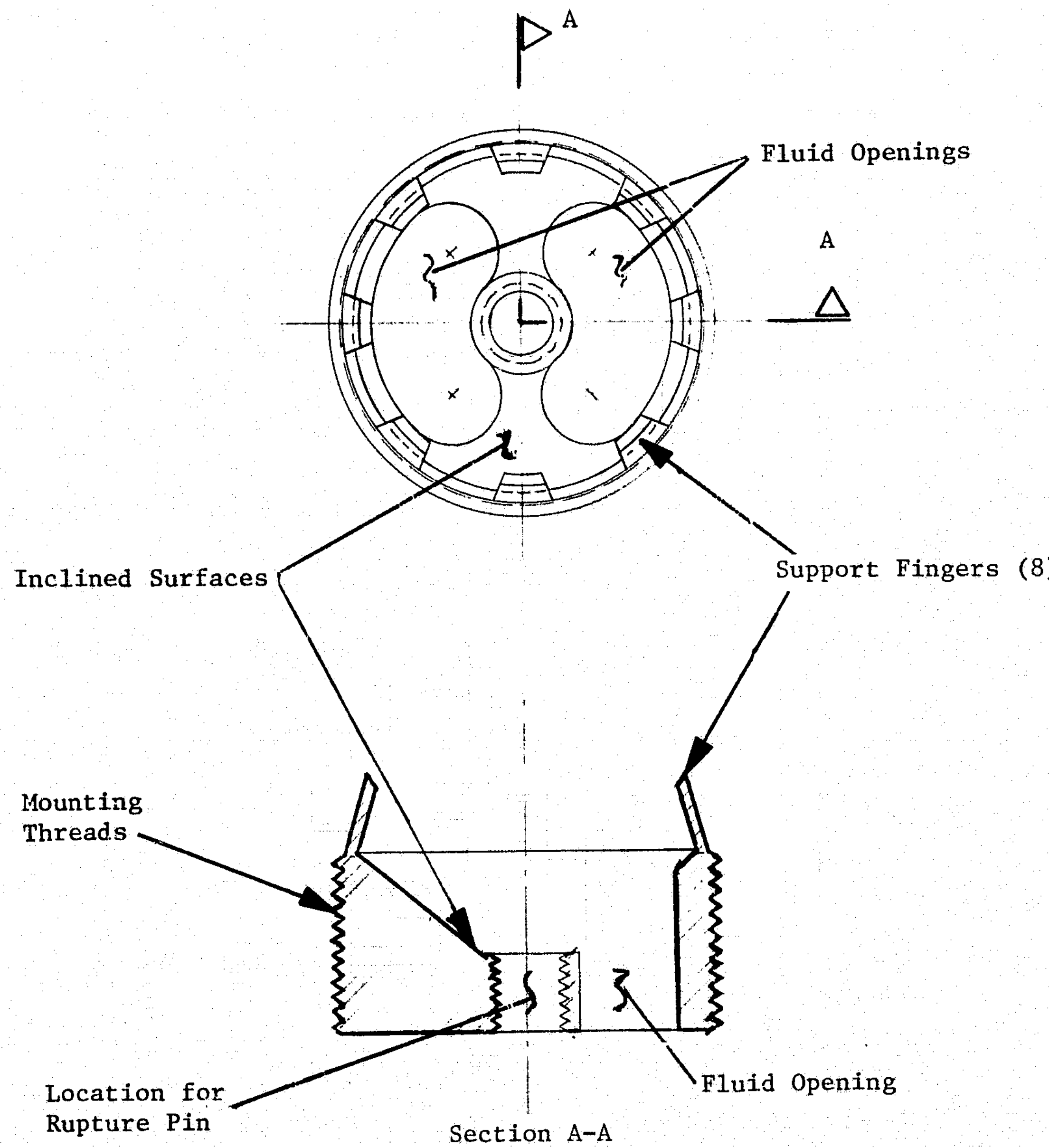


Fig. III-9 Capsule Holder Details - Nutrient/Reagent Injector

4. <u>Assembled Module</u>

After welding the top and bottom plates onto the water jacket, the titanium isolator was mounted on the top, the cap assembled to the isolator, and all the mounting holes drilled and fitted with helicoils. All the wires from the seven heaters, four temperature sensors, and three injector actuation indicators were attached to the two 9-pin connectors via miniature jack and pin disconnects. A front and rear view of this fully assembled module is shown in Figure III-10. This module was tested as described in Section IV-C.

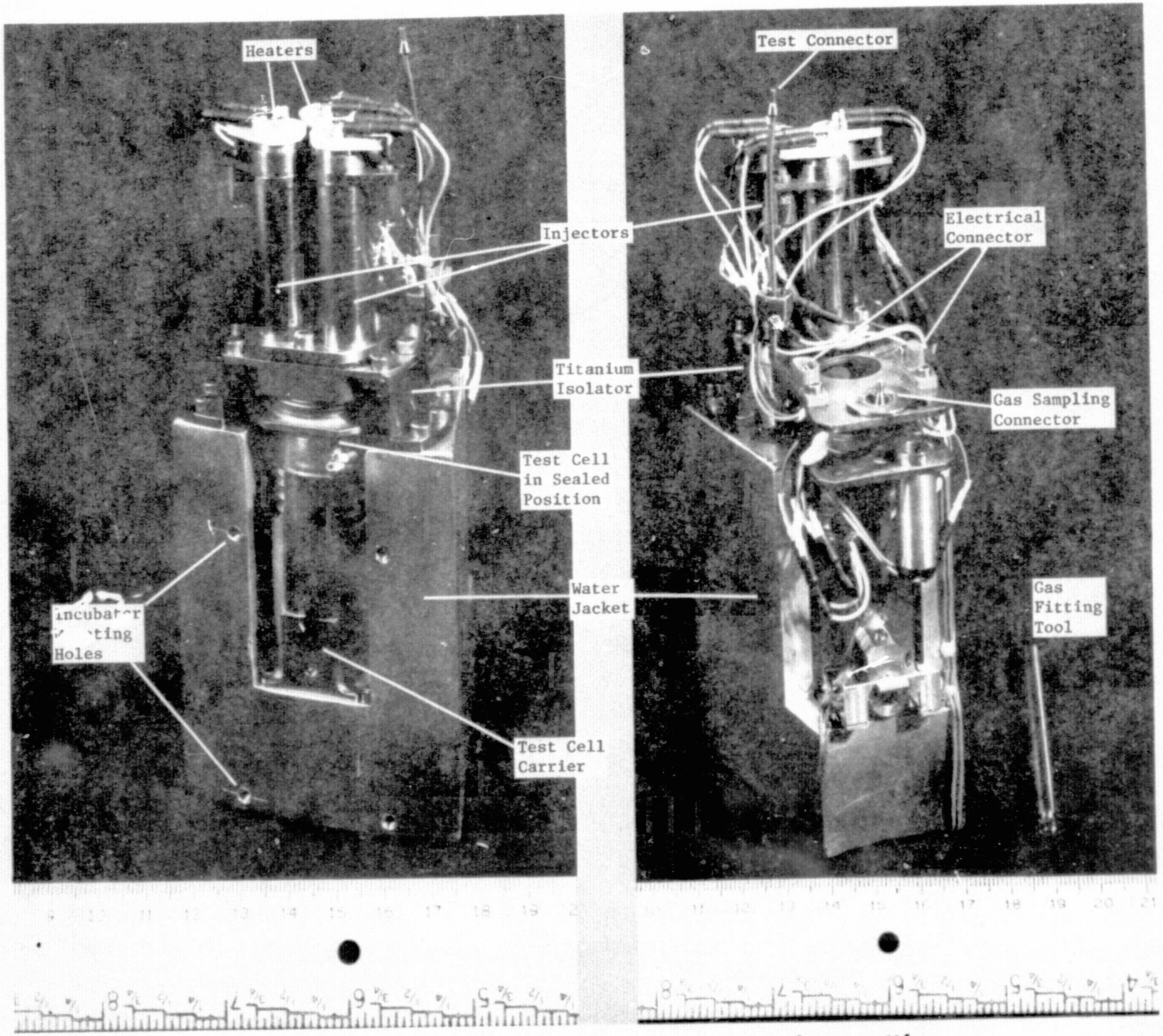


Fig. III-10 Fully Assembled Test Cell Module - Front and Rear Views

5. Incubator

The basic structural element for assembling the test cell modules, gas analysis subassembly, seal drive mechanism, and soil distribution assembly is the incubator box which, as its name implies, provides the enclosure for maintaining the incubation temperature for the test cell modules. This incubator also contains the heat exchanger coil and blower assembly for circulating the cooling gas through the heat exchanger and the external radiator. The present state of construction of this incubator is seen in a bottom view in Figure III-11 with the test cell module installed. This view shows the structure for mounting the seal drive assembly and mounting locations for two more modules. Mounting locations for the remainder of the modules will be added as development progresses. A top view of the incubator with the module installed is seen in Figure III-12. A partially completed gas analysis manifold is shown in place with the 11 gold gas sampling tubes and the mass spectrometer inlet tube.

B. ELECTRONIC DESIGN AND FABRICATION

A complete thermal control system was designed to control the temperatures of the test cell and cap in the module, control the preheating and injector firing for the three injectors, and to control the operational sequence of events. These circuits were fabricated in breadboard form and mounted on a 1 3/4 in. standard rack panel as shown in Figure III-13.

1. Soil Temperature Control

The circuits used to control the temperature of the test cell and cap at preselected temperatures are shown in Figure III-14. In order to eliminate power conversion losses, the heaters are powered directly from the primary power bus. There is a system requirement that circuit common (which is connected to the lander interface common) must be isolated from the power bus. This isolation is accomplished through the use of light-coupled isolators. These consist of a light emitting diode and photodiode packaged together in a transistor can. They are smaller and lighter than transformers.

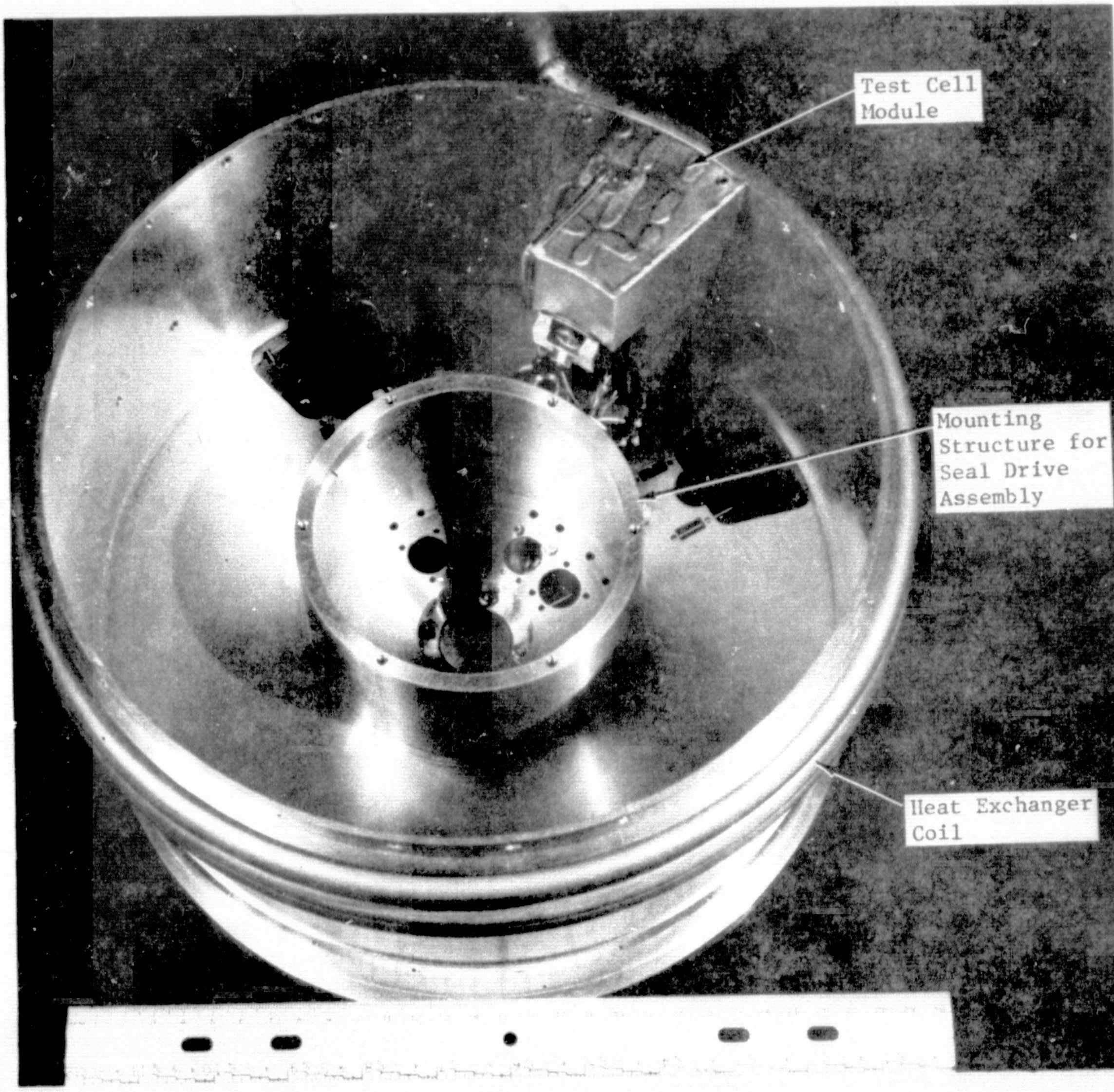


Fig. III-11
Underside View of the Incubator Housing with a Test Cell Module Installed

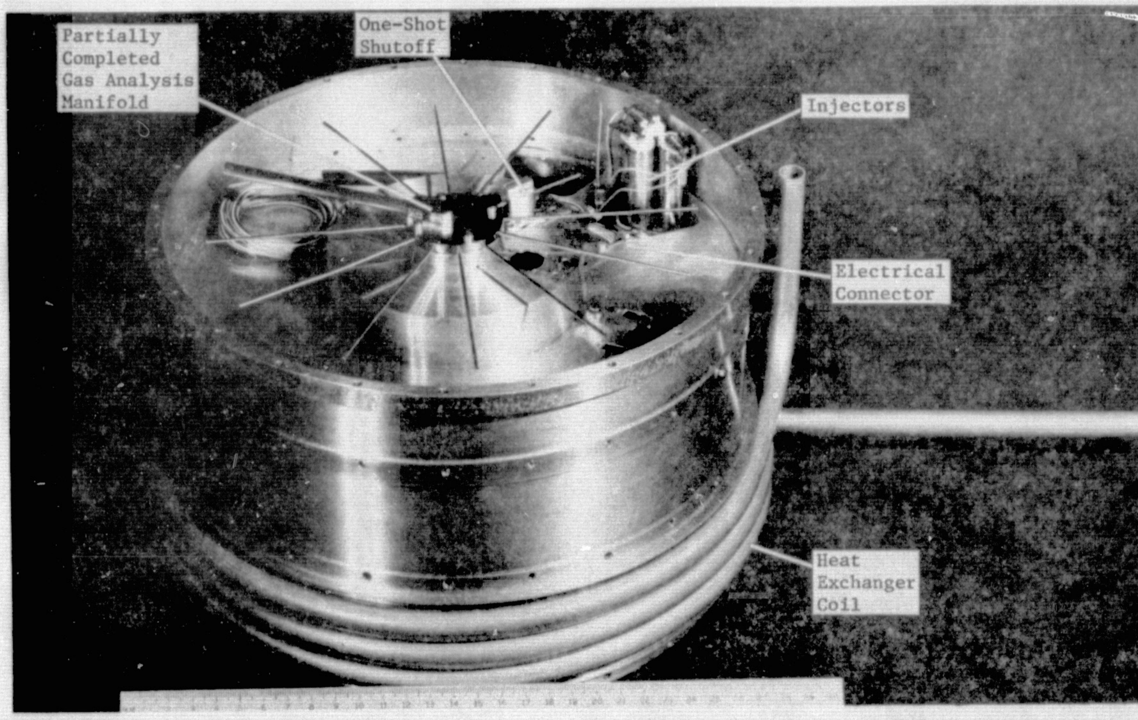


Fig. III-12 Top View of Incubator with Test Cell Module Installed

The bus voltage can vary from 24 to 37 V. This voltage is effectively regulated to 22 VRMS by a pulse width modulator heater power preregulator control circuit which is common to all heater controllers. This circuit generates a control signal mixed with each heater controller error amplifier output which is pulse width modulated at a much lower rate.

The preregulator acts to hold the $e^2 \tau/T$ constant within 5%. The quantity e is any value of supply voltage from 24 to 37 V and τ/T is the duty cycle of the resultant waveform. Since T is constant as determined by the clock pulse rate, τ must be decreased proportional to the square of the bus voltage.

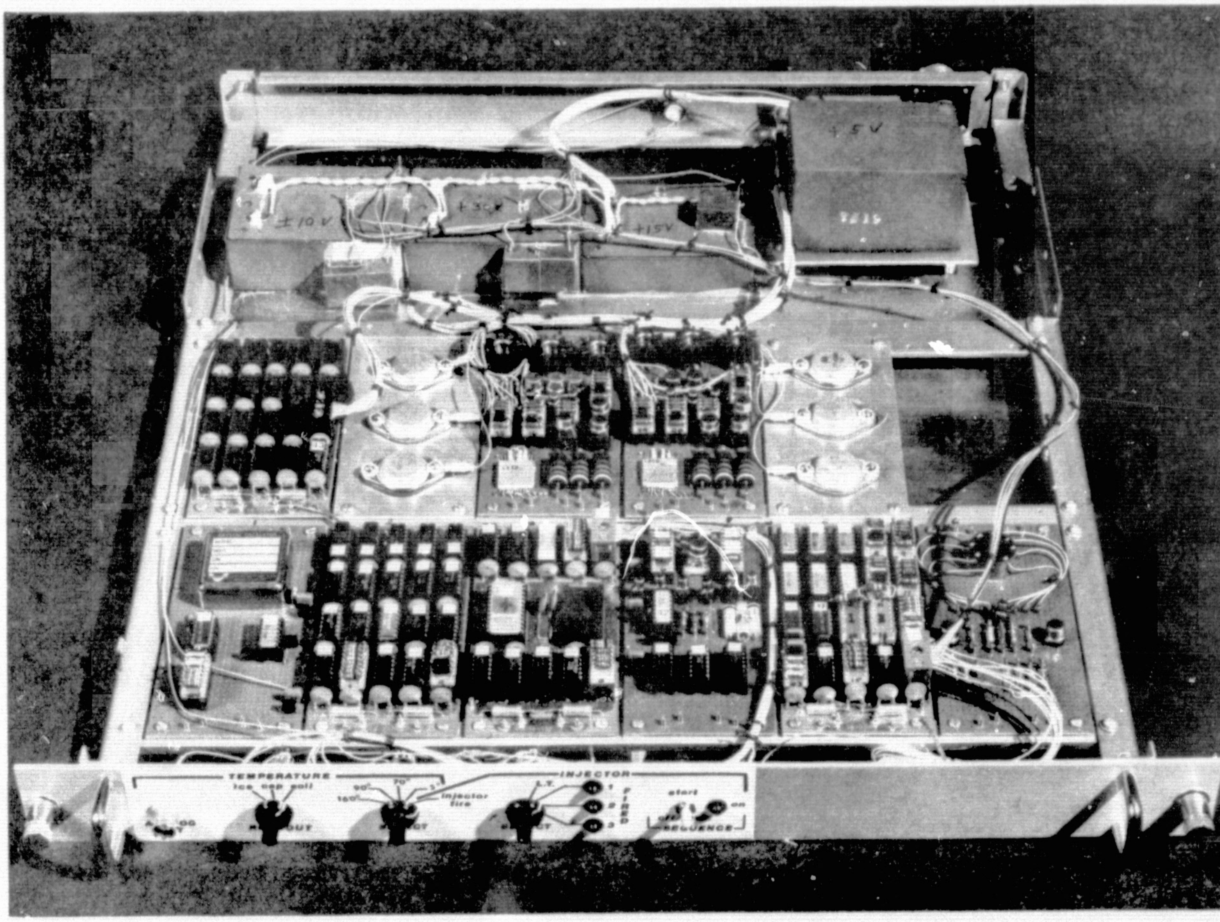


Fig. III-13 Thermal Control and Injector Control Electronics

The circuit actually applies a straight line correction so the RMS value $e^2\tau/T$ is not exactly constant over the input voltage range. The 5% tolerance accounts for this deviation plus an allowance for circuit drift.

The duty cycle of each heater waveform is automatically adjusted to maintain the thermally controlled elements to within $2^{o}C$ of their set point temperature.

The temperature select switch is used to pick the desired set point for the cell and cap heater controllers. At the present time, this includes selection of $160^{o}C$, $90^{o}C$, $70^{o}C$, and $5^{o}C$. Other set points can be added by simply adding the required resistors to the proportional controller bridge. The basic

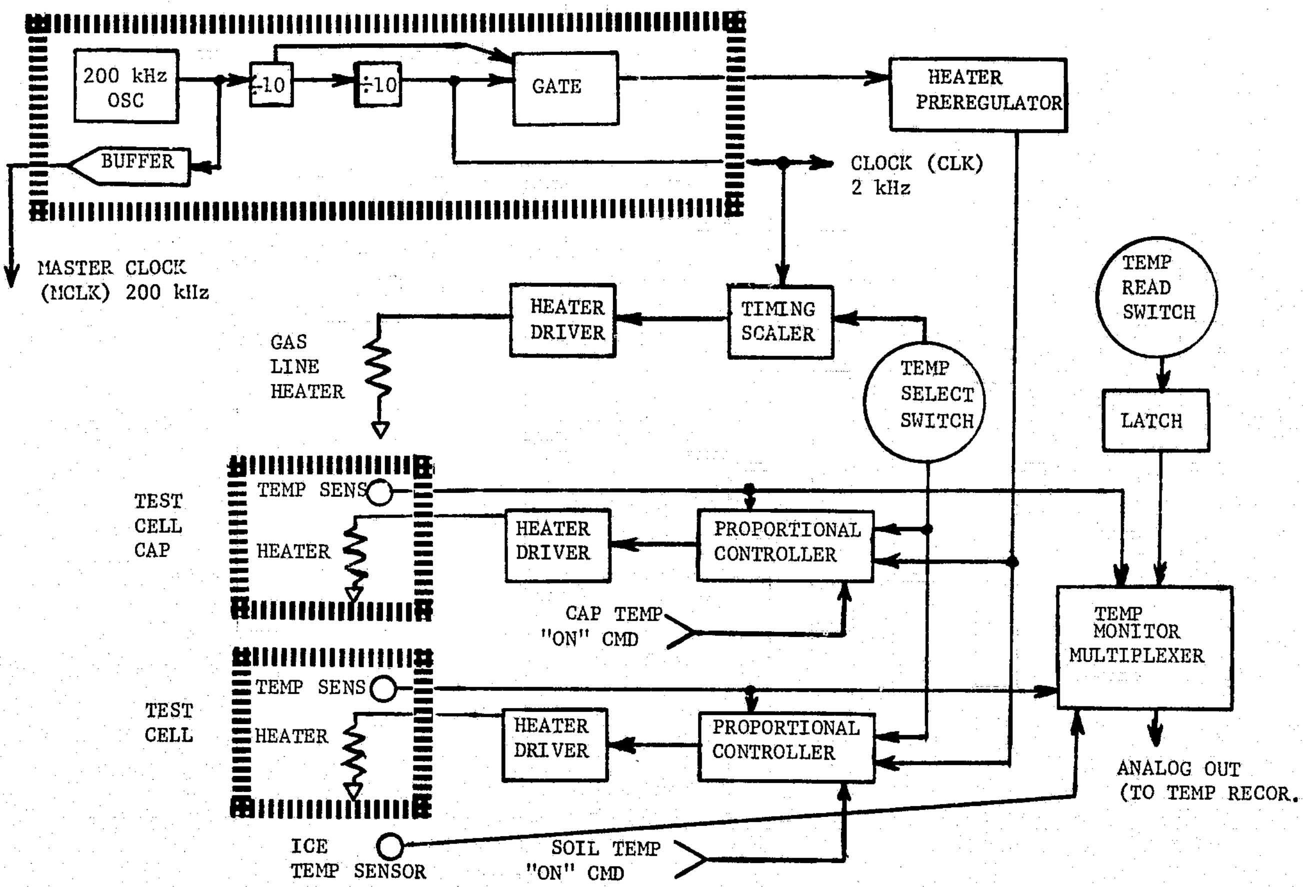


Fig. III-14 Soil Temperature Control

circuits used in these heater controllers are those designed and built for the Viking '75 biology experiment.

The Kapton encapsulated heater for the gas sampling line does not have a proportional controller. It is operated at a preset power and duty cycle value since its primary purpose is not to maintain a specific temperature, but to prevent condensation in the gas sampling line. It is heated during and for a set time following any heating program for the test cells.

2. Injector Sequence

When firing an injector, a sequence of events is followed to ensure proper injection. The first requirement is that the soil, test cell, cap, and injector temperatures all be above

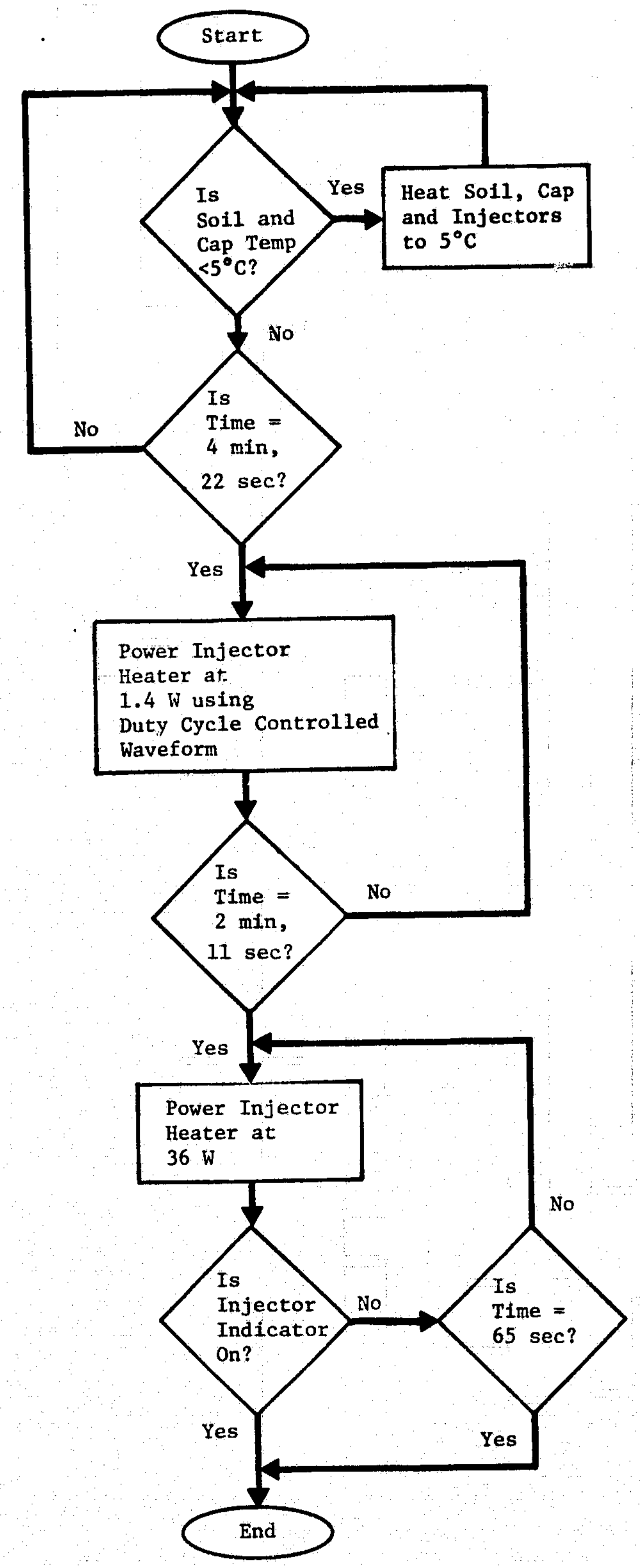


Fig. III-15 Injection Mode Sequence

the water freezing point. Then the injector is preheated to raise the capsule internal vapor pressure to an adequate expulsion pressure. Finally, the heater is fully turned on to melt the Sn/Sb spacer and actuate the injection. The program sequence for these functions is shown in Figure III-15

Step one is to test the soil and cap temperature to see if the temperature is above or below 5°C. If it is below then the cap, test cell, and injector heaters are turned on until the cap and test cell sensors indicate 5°C. Then the injectors are heated for a preset time at 1.4 W, as determined by the thermal computer program results described in Section II-B.5, to provide the necessary expulsion vapor pressure. Finally, the injector power is turned on to the full 36 W until the actuation indicator switch shows that the Sn/Sb spacer has melted and presumably allowed the capsule to rupture. A maximum time of 65 sec is programmed into this full power step as a backup. The nominal time for actuation is about 40 sec.

This program is stored in the programmed memory (PROM IM5623) shown in the injector sequence circuit block diagram in Figure III-16. The logic programmed into this mode and the programmer "truth" table are shown in Tables III-1 and III-2 respectively.

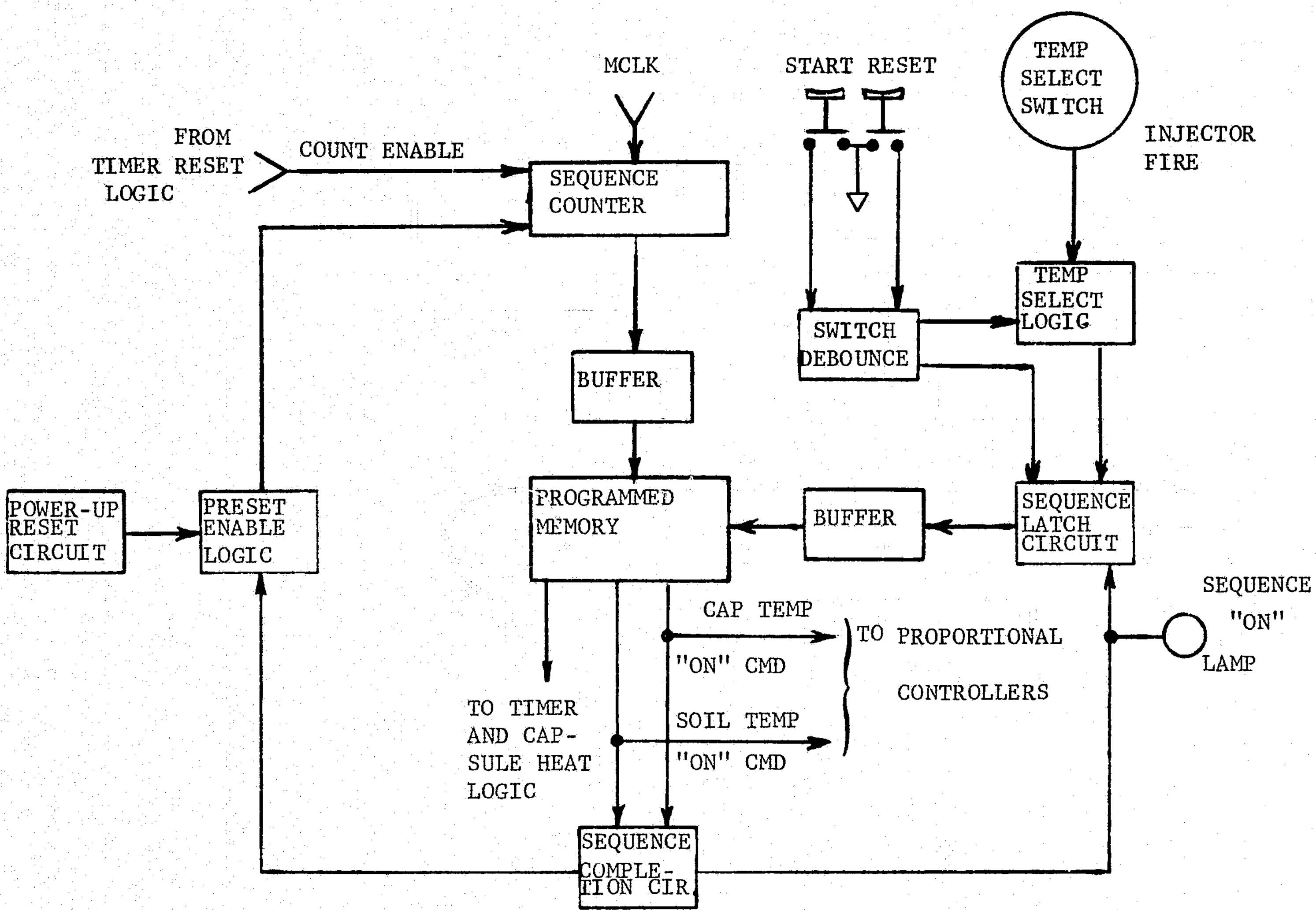


Fig. III-16 Injector Sequence - Circuit

Table III-1 Injector Sequence Mode Logic

1. Step Counter Enable (SCE)

   SCE = $\overline{TR}$ (For TR definition, see Timing and Capsule Select Circuit)
   Using this, step counter will be stepped at the same leading edge of the MCLK that causes the timer to reset.

2. Step Counter Preset Enable (CPE)

   a) Initial Preset to Zero (IPZ)

   Define: Power-up Reset = PUR $\Rightarrow$ Lo Hi
   IPZ = PUR

   b) Mode Complete Preset (MOC)

   MOC = $O_1 \bullet O_2$

   So: CPE = PUR + MOC = $\overline{\overline{PUR} \bullet \overline{MOC}}$

3. Mode Latch Strobe (MLS)
   MLE - Start Pulse

4. Mode Latch Reset (MLR)

   MLR - MOC + Reset Sw + $\overline{\text{Mode 5}}$ = $\overline{\overline{MOC} \bullet \overline{\text{Reset Sw}} \bullet \overline{\overline{\text{Mode 5}}}}$

   Item 2b

5. TTL Driving COSMOS (IM5623 Outputs Driving CMOS)
   Pull-up Resistor Required

$$R_{min} = \frac{V_{DD_{max}} - V_{OL_{max}}}{I_{OL}} = \frac{(5.5 - 0.45)}{16m} = \frac{5.05}{16m} \approx 318\,\Omega$$

+1 -3

$$R_{max} = \frac{V_{CL_{min}} - V_{IH_{min}}}{N\ I_{CEX_{max}}} = \frac{(4.5 - 3.5)}{5\ (10\mu a)} = \frac{1}{50\mu} = 0.02\ M - 20k\,\Omega$$

   Let pull-up resistor = 4.02kΩ for medium speed and low power dissipation.

6. Temperature on Commands Definitions
   Soil Temperature on Command $\Rightarrow$ STOC
   Cap Temperature on Command $\Rightarrow$ CTOC

Table III-2 IM5623 PROM Programming Table for Injector Sequence Mode

Step Description	Signal for Next Step	Mode MSB A7	A6	A5	Capsule Select A4	A3	Mode Steps MSB A2	A1	A0	Injector and Timer O_4	O_3	Cap Temp O_2	Soil Temp O_1
All Modes Quiescent	Start	0	0	0	0	0	0	0	0	0	0	0	0
*Start Soil and Cap Temperature Start 5 min Time	End 5 min Time	1	0	1	0	0	0	0	0	0	1	1	1
Injector Capsule Heater at 1.4 W	End 5 min Time	1	0	1	0	0	0	0	1	1	0	1	1
Injector Capsule Heater at 36 W	End 1 min Time or Indicator Sw	1	0	1	0	0	0	1	0	1	1	1	1
Mode 5 Quiescent	O_1, O_2 Resets PROM	1	0	1	0	0	0	1	1	0	0	1	0

*Will require injector beaters to be on at .5 W. So will Gate 1 of 72 pulses out of timer for 5 min.

O_4	O_3	Result
0	0	None
0	1	5 min Timer (Soil and Cap Heat)
1	0	Injector 5 min Timer (Preheat)
1	1	Injector 1 min Timer (Fire)

3. Timing and Capsule Select Circuits

The circuits to drive the injector heaters and logic to respond to the actuation indicators, the logic to determine the heater duty cycle for the type of heating desired, and the selection of which injector is to be actuated are shown in Figure III-17. The three driver circuits for the heater transistors used for the injectors and those used for the test cell, cap, and gas line heaters are all contained in two hybrid driver packages fabricated as relay drivers in the Martin Marietta microelectronics laboratory.

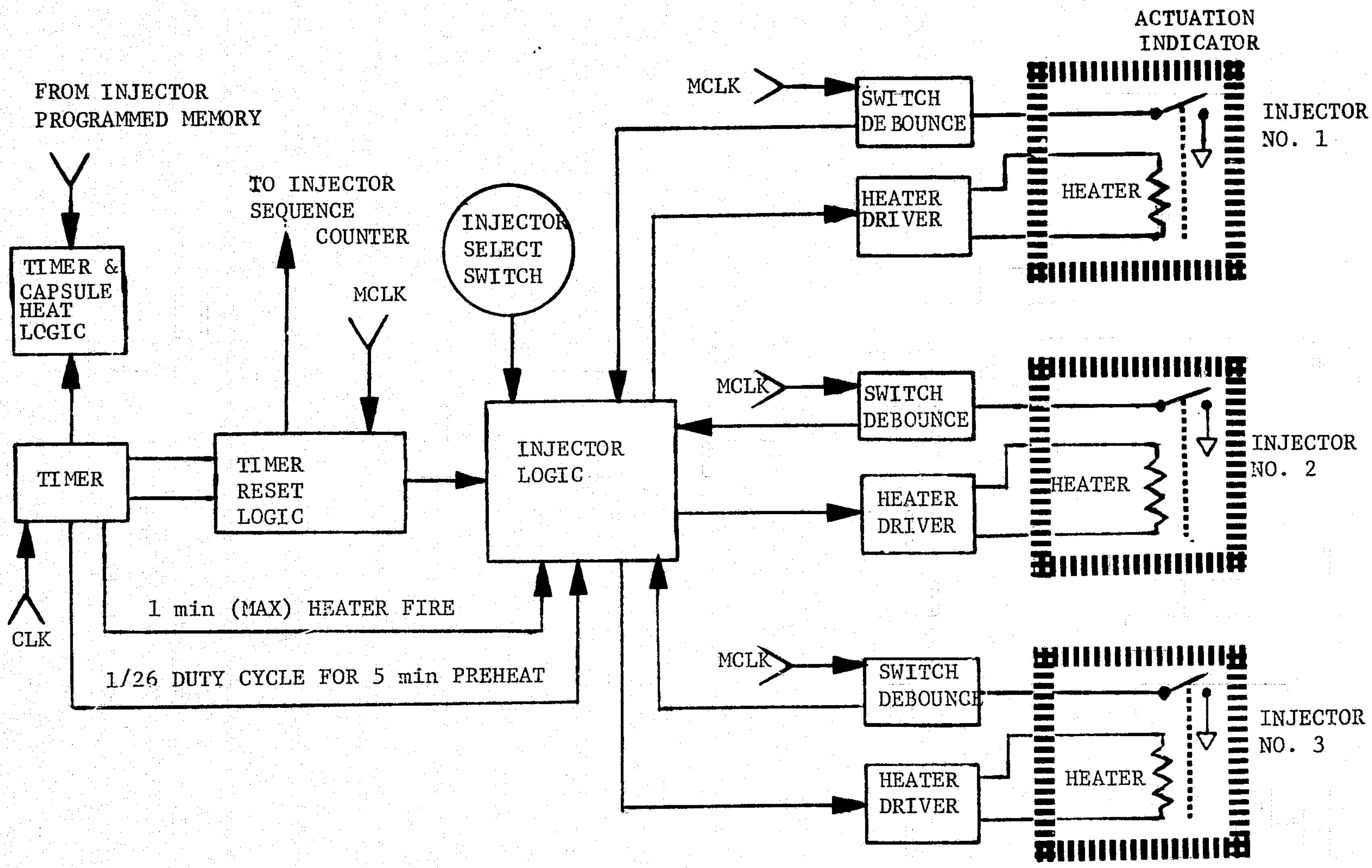


Fig. III-17 Timing and Capsule Select Circuit

IV. PERFORMANCE TESTS

In addition to the specific development tests used throughout to evaluate the performance of design concepts, tests were specifically devised for the injectors, the cooling system blowers, and the assembled test cell module.

A. INJECTOR VOLUME REPEATABILITY

A series of tests were performed with water-loaded injector capsules to determine the reliability of delivery of fluid into the test cell. In these tests the USMLD engineering model was installed in a vacuum bell jar. The quartz capsules were loaded with water by the method reported in the November 1974 Final Report MCR-74-421, as mentioned in section III-A.3. Each protocapsule was weighed before filling. The two separated parts of the protocapsule were weighed after loading and sealing to determine the exact quantity of water loaded.

After sealing and weighing the capsules, they were all placed in a vacuum system and left for 20 hr and reweighed afterward. The weights agreed to within $\pm$ .5 mg with the weights before, indicating no leakage out of the sealed capsules.

Three such capsules were mounted into the three injectors and installed on the test cell cap. Thermocouples were attached to the walls of each of the injectors and the bell jar was evacuated to the selected test cell pressure (4, 10, 25, 50, 100 torr). After reaching the desired pressure, the seal drive system was actuated to seal the test cell. The injectors were installed with their actuation micro switches in series with the heater such that it opened the heater circuit at the moment that the Sn/Sb retainer ring melts and allows the mechanism to move downward to rupture the quartz capsule. The nominal power for firing the injectors was 43 W for about 45 sec. The temperature of the housing was recorded at the time of firing and at its maximum value which was usually reached about 60 sec after firing. The firing temperatures were about 40°C and the maximum about 57°C. It is not certain what is the exact value of the fluid temperature inside the capsule, but it is expected that the housing temperature reasonably well represents the fluid temperature with a slight phase lead.

The test cell was removed and weighed after each firing to determine the quantity of water delivered.

Each protocapsule was numbered and logged in the data book as it was loaded. A record of the disposition of each capsule from 1 through 38 is given in Table IV-1. The table illustrates the learning process in developing the technique of loading the capsule with water, sealing and separating the capsule, degassing by freezing and thawing, assembling into the injector, mounting in the test cell cap, pumping down the bell jar, actuating the injector, and weighing the water delivered. At first, the sealed tips were too long to fit in the injector piston (see Figure III-7). A new technique of heating closer to the shoulder proved successful in solving this problem. Capsules seven and eight cracked while freezing due to pouring the LN_2 over the capsule instead of raising the LN_2 container up to the capsule as was done subsequently. Random failures during sealing amounted to five capsules out of 38, or 13%. Random failures during assembly and delivery due to faulty placement of the rupture pin (5 cases) could be improved by procedure control. One capsule, (No 27) failed to break on two tries although the conditions were all proper. This suggests that perhaps the bottom was too thick on this capsule and that a method for nondestructive testing of the bottom thickness should be developed. One possibility is a needle micrometer to fit through the neck of the protocapsule before loading and sealing. Another is an X-Ray backscatter technique.

A total of 19 capsules were successfully ruptured and their delivery percentage measured. There were four deliveries at each of four pressures in the test cell, 4, 10, 25, and 50 torr and three at 100 torr. These results are summarized in Table IV-2. The sixteen tests at pressures up to 50 torr demonstrated very successful delivery with 74.7 to 94.4% of the fluid in the capsule being delivered into the test cell.

Three capsules at 100 torr delivered 84.2% and 68% and 6.8%. The latter result implies that the water temperature in the capsule had not reached a high enough value for its vapor pressure to exceed the 100 torr in the test cell. In the other firings at 100 torr, a cracking at the top of the capsule occurred as well as the usual bottom rupture. This equalized the pressure inside the capsule and allowed the 84.2% and 68% delivery. These tests were all performed without preheating

Table IV-1 Injector Capsule Load, Assembly, and Delivery Record

Capsule	Load & Seal	Assemble	Deliver	Pressure (torr)	% Delivered	Comments
1						Upper tip too long
2						Upper tip too long
3						Broke while scaling
4						Upper tip too long
5						Broke while sealing
6				100	84.2	Top cracked
7						Cracked while freezing
8						Cracked while freezing
9				4	77.0	
10						Broke during pumpdown; pin too close
11						Forgot to mount test cell
12				4	77.6	
13				10	80.1	
14						Top broke; pin not close enough
15				50	78.9	
16						Cracked while freezing
17				10	80.8	
18				25	93.6	
19				25	83.2	
20				50	88.5	
21				50	94.4	
22						Broke during assembly; pin too close
23				50	74.7	
24				25	93.7	
25						Bottomed on support; pin not close enough
26				25	84.3	
27						Capsule didn't break - two tries
28						Broke while sealing
29						Broke during assembly; pin too close
30						OK delivery; weighing failure
31						Broke while sealing
32						Broke while sealing
33				4	85.6	
34				4	89.6	
35				10	91.0	
36				10	86.5	
37				100	68.0	Top cracked
38				100	6.8	

of the capsule before delivery since the heater assembly experienced some problems when preheating attempts were made. The problem was associated with softening of the plastic actuator button on the switch. A ceramic button would solve this problem. Subsequent tests could be performed at 100 torr with preheating. The temperature required for the water vapor pressure to exceed 100 torr is 54°C.

Table IV-2
Injector Test Summary

CAPSULE NO.	TEST CELL PRESSURE, torr	ELECTRIC POWER, W	TIME TO FIRE, sec	TEMP AT FIRE, °C	TEMP. MAX	DELIVERED WATER (CC)	(%)	
9	4.0	29	60	-	-	0.829	77.0	
12	4.1	26	116	49	54.4	0.943	77.6	
33	4.0	46	60*	45.6	68.3	0.936	85.6	
34	4.1	43	48	38.5	56.2	0.989	89.6	
13	9.4	34	75*	57.2	66.0	0.853	80.1	
17	9.8	35	83*	72.0	80.2	0.906	80.8	
35	10.1	44	43	34.7	54.3	1.004	91.0	
36	10.0	46	42	41.3	57.4	0.975	86.5	
18	25.0	37	42	43.0	61.8	1.051	93.6	
19	24.6	43	45	-	-	0.925	83.2	
24	25.2	43	70*	58.9	77.9	1.039	93.7	
26	24.7	45	40	35.6	57.8	0.938	84.3	
15	50.0	38	90*	76	90.1	0.866	78.9	PREHEATED
20	49.6	43	63	52.9	75.3	0.983	88.5	
21	49.2	39	91*	80	91.5	1.042	94.4	
23	49.7	43	37	34.1	55.0	0.841	74.7	PRE-HEATED
6	100.0	29	45	67.0	81.4	0.890	84.2	TOP CRACKED
37	97.5	46	43	42.5	61.8	0.759	68.0	TOP CRACKED
38	99.9	46	50*	55.8	71.1	0.076	6.8	

*INDICATES HEATER CURRENT WAS SHUT OFF MANUALLY WHEN VISUAL ASPECT INDICATED APPARENT FIRING BUT SHUT-OFF SWITCH HAD NOT FUNCTIONED.

B. COOLING SYSTEM BLOWER

Blower tests were performed with a closed gas system designed to simulate the flow versus pressure drop characteristics of the USMLD coolant loop and radiator/convector coil. The blower housing was designed to totally contain the motor in the high pressure volume of the system in order to eliminate the need for a rotary shaft seal (Figure IV-1). Two Globe motors (P/N A9A-608-3 and P/N 41A210) were tested with two different impeller types (8-vane paddle wheel and 10-vane forward curve shown in Figure IV-2). Both impellers were of the squirrel cage type with outside diameter of 0.94 in. (23.8 mm) and length of 0.63 in. (16.0 mm). The impeller housing was constructed with the proper logarithmic curvature for this

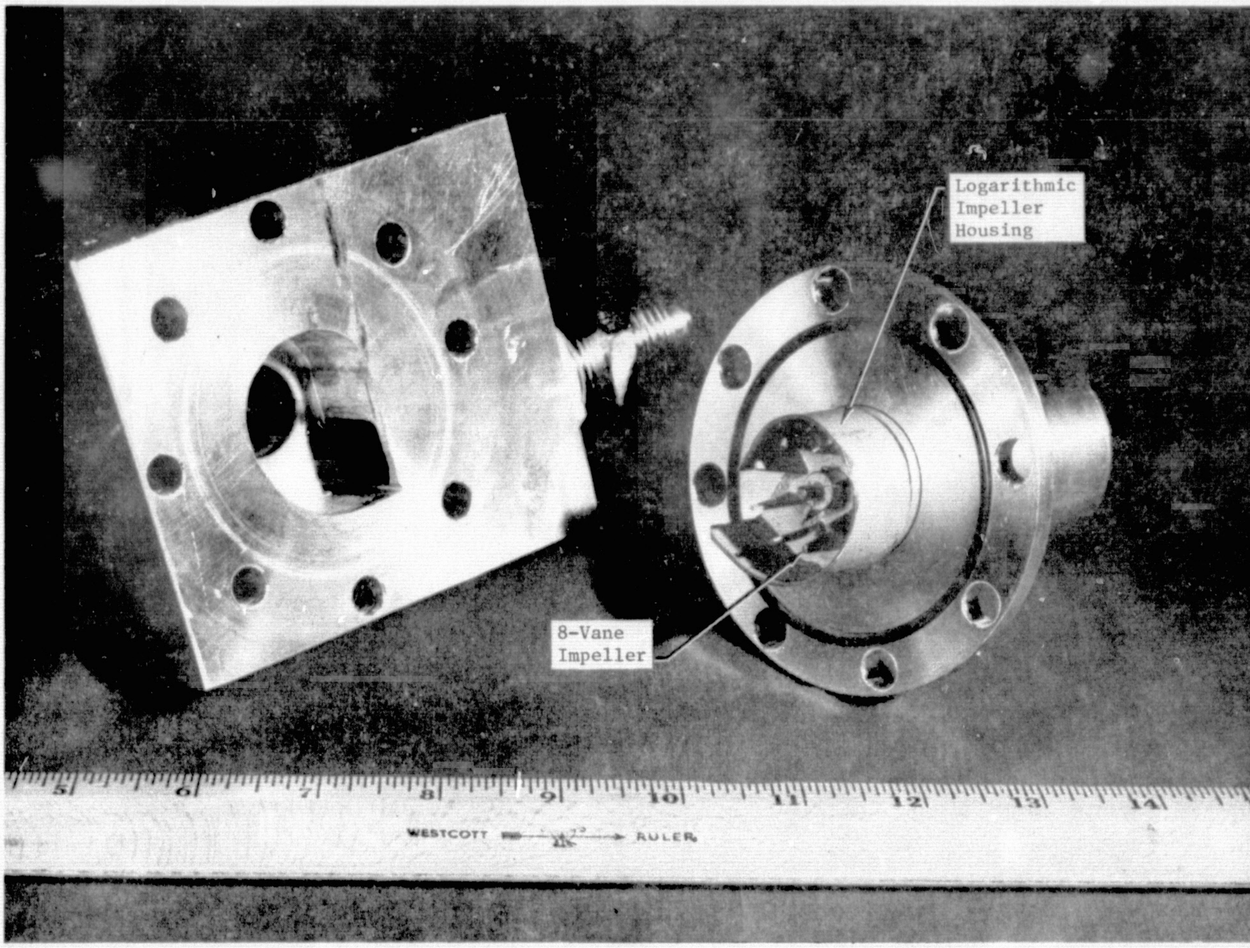


Fig. IV-1
High Pressure Housing for Cooling System Blower Tests

type impeller. The two motors (with impeller) had masses of 160 gms (A9A-608-3) and 59 gms (41A210) and unloaded rotation speeds at 24 Vdc of 11,050 rpm and 17,200 rpm respectively. The smaller motor (PN41A210) with the 8-vane impeller (Figure IV-3) was the combination which resulted in the most efficient operation for the cooling system.

The higher speed motor was considerably more efficient in providing the required 5.0 kg/hr (11.0 lb/hr) mass flow. For example, at a system pressure of 9.3 atmospheres the larger motor required 2.68 W to pump 5 kg/hr while the smaller motor needed only 1.30 W for the same flow. The 8-vane paddlewheel impeller was slightly more efficient than the 10-vane forward curved type with the latter requiring 1.50 W instead of 1.30 W

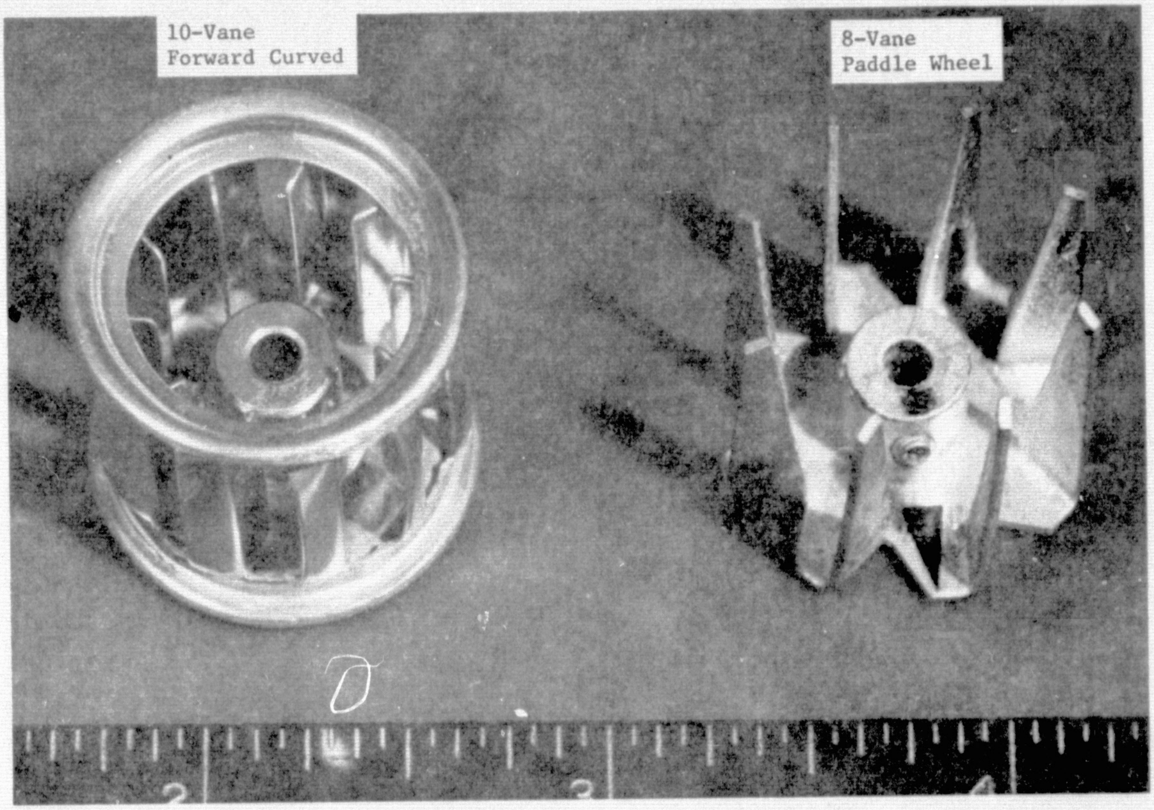


Fig. IV-2
Two Impeller Types Tested in Cooling System Blower Tests

at 9.3 atmospheres system pressure. A parametric summary of the blower test data for the small motor (41A210) with the 8-vane paddlewheel impeller is given in Figure IV-4. The data at 9.3 atmospheres for the large motor with the 8-vane impeller are also shown for comparison, illustrating the considerably higher power needed to achieve the required system flow rate of 5 kg/hr.

As expected theoretically, the higher system pressure yields a more efficient flow so that a design choice of approximately 9.3 atmospheres (125 psig or 9.4×10^5 Pa) is chosen as a compromise between efficiency and necessity for safety precautions.

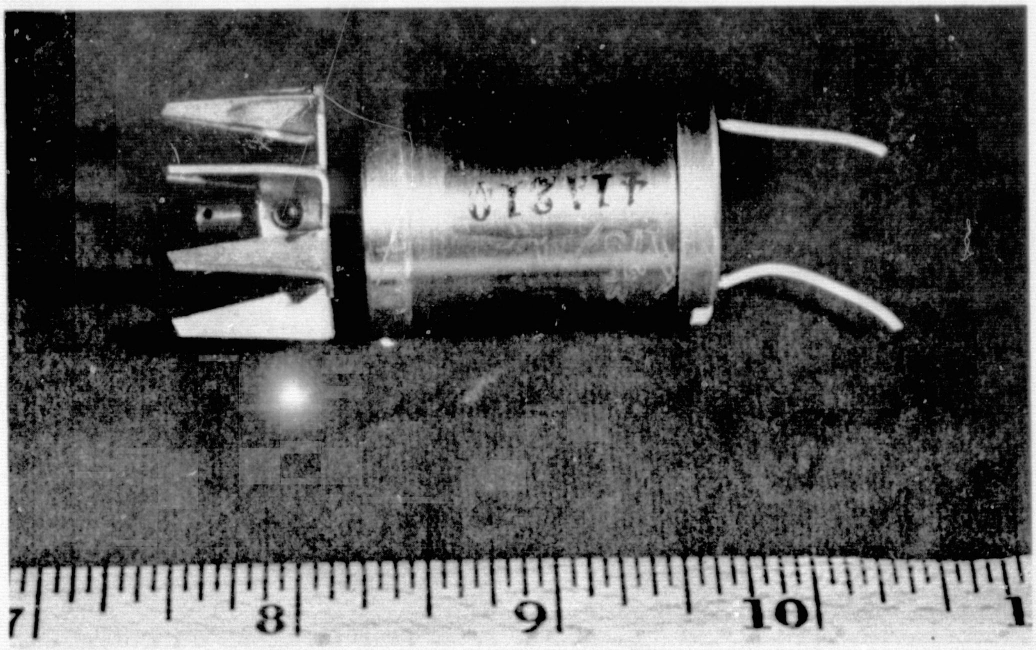


Fig. IV-3
Smaller, Higher Speed Blower Motor (PN 41A210) with 8-Vane Impeller

The test assembly used a 4.8 mm diameter oriface in series with the blower. At 5 kg/hr nitrogen mass flow rate, we see from the data of Figure IV-4 that this oriface yields a pressure drop of about 475 Pa (1.9 in H_2O) when the system pressure is 9.3 atm (9.4 x 10^5 Pa). A theoretical calculation of the system pressure drop for these conditions yielded only 187 Pa (0.75 in H_2O). This is calculated for a total system length of 10.7 m of 1/2 in. (1.27 cm) tubing with 0.020 in. (0.51 mm) walls. The 10.7 m corresponds to a 7.8 m long radiator (Section II-B.6), 0.25 m diameter 3-turn heat exchanger, and 0.5 m interconnection tubing. Thus, the system tests were performed with a simulation more severe in pressure drop than that calculated for the anticipated cooling system. Therefore, the test results represent a conservative estimate of the electrical power requirement for the cooling system.

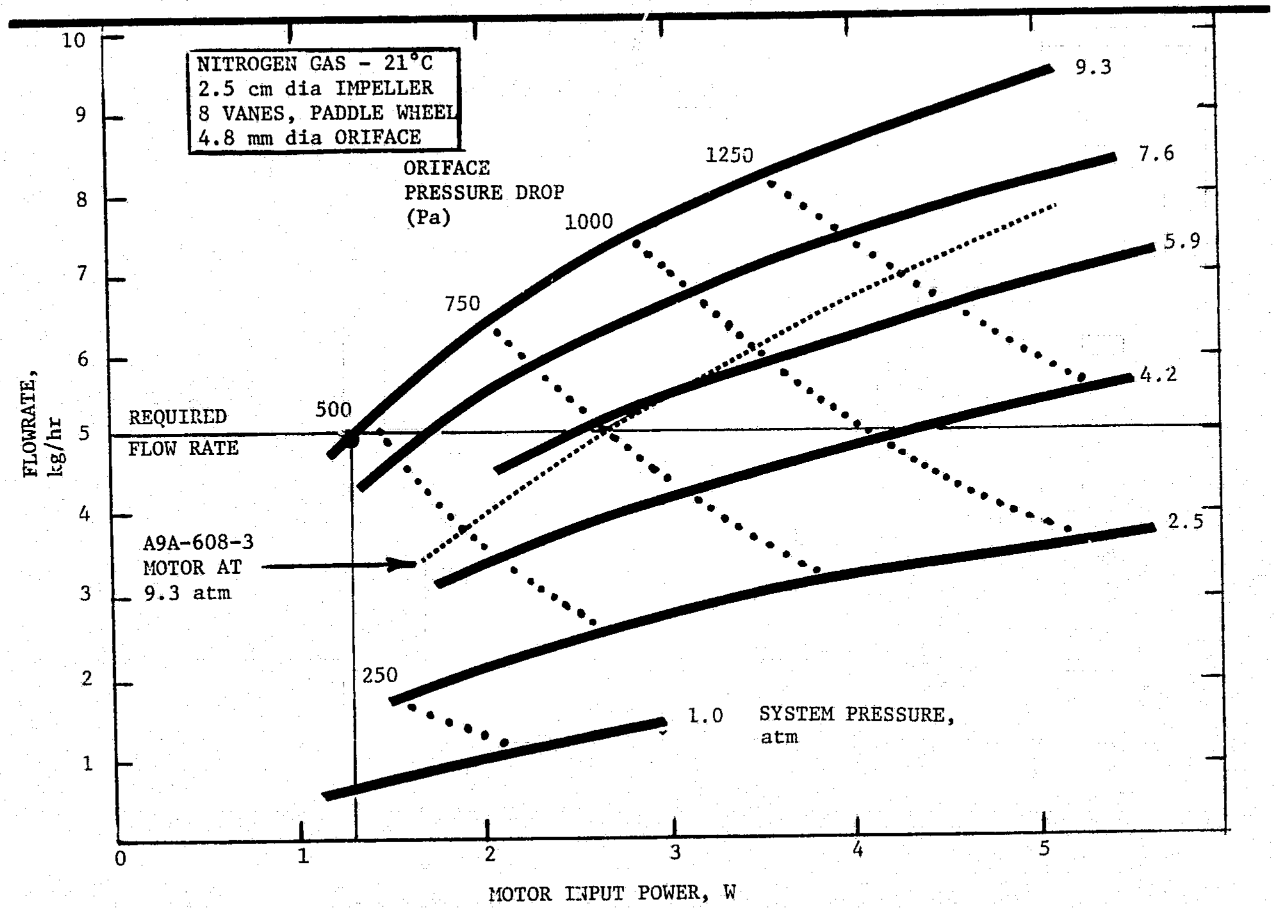


Fig. IV-4
Flow Rate versus Motor Power for Motor No. 41A210 (and A9A-608-3) - 8 Vane Impeller

The flowrate results for the 1-vane forward-curved impeller with the small motor are given in Figure IV-5 showing essentially the same type of performance as the 8-vane impeller but with slightly decreased efficiency as noted above. These curves also show the voltages applied to the motor to achieve the resultant flows.

In summary, these tests have demonstrated a design point of 1.3 W as a conservative upper limit of the power required to operate the cooling system at a system pressure of 9.3 atm of nitrogen.

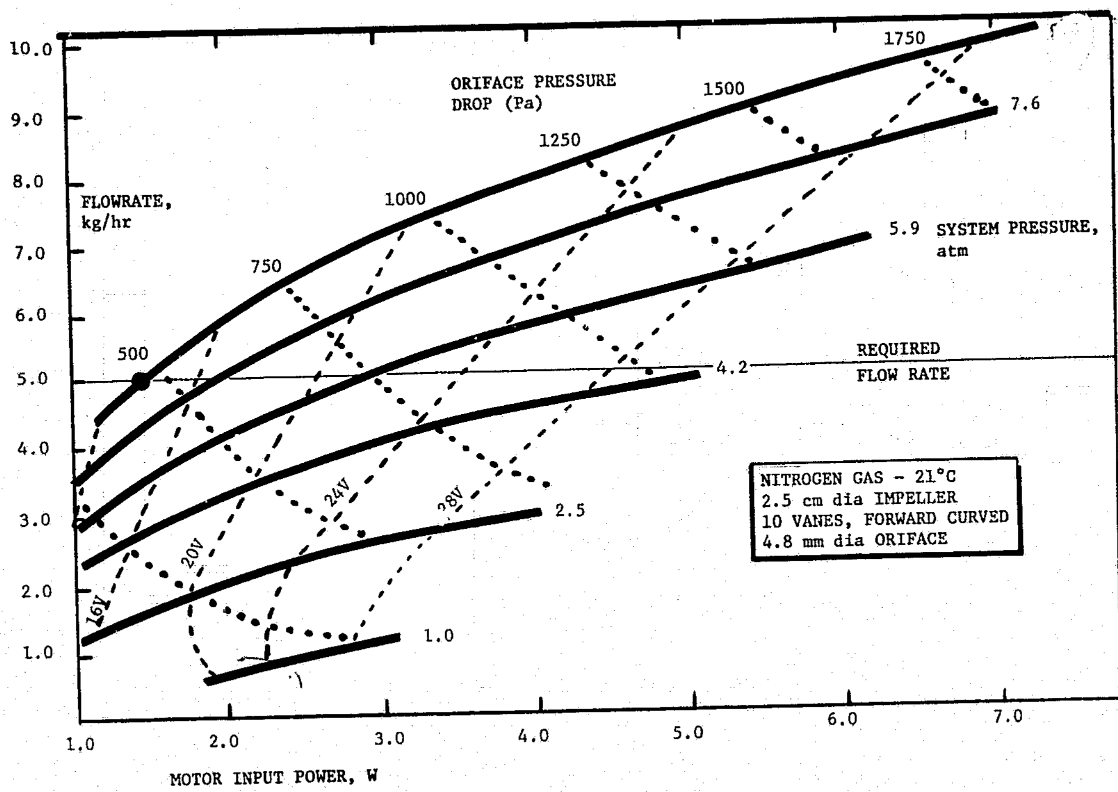


Fig. IV-5 Flowrate versus Motor Power for Motor No. 41A210 with 10 Vane Impeller

C. MODULE VERIFICATION

1. <u>Water Jacket</u>

The first step in verifying the integrity of the module involved attaching a helium leak detector to one water fill hole of the water jacket and sealing off the other one. This check verified that the welding of the water jacket had produced a leak-tight container with no leak observable within the sensitivity (1.70 x 10^{-10} cm^3/S He) of the leak detector. Following this test, the water jacket was filled with a carefully measured quantity of water. The geometry calculations for the jacket had indicated a capacity of 90.4 gms and the measured fill was 90.0 gms.

After loading with water and sealing the fill holes with epoxy, the water jacket was placed in a freezer overnight. The dimensions of the jacket were measured before freezing and again afterwards. They were found to agree within 0.010 in. (0.25 mm).

No sign of swelling could be detected with a straighedge on the flat sides.

2. Test Cell Vacuum Seal

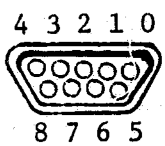
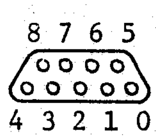
The test cell, fitted with its gold gasket and gasket retainer, and with its two belleville spring washers was mounted in the test cell carrier. The cap and isolator were mounted on the water jacket. The geared swagelock nut was mounted on the gas sampling tube fitted with a blind plug and a regular swagelock nut was fitted to the leak check tube. The three injectors were fitted with gold gaskets and attached in place in the cap. The helium leak detector was attached to the leak check tube.

The first check indicated a leak at the test cell seal. After checking the dimensions and introducing the proper shims to achieve the design compression of the belleville washers the system was leak checked again. This time the leak detector showed no indication of leakage to its sensitivity limit of 1.70×10^{-10} cm^3/s He. The requirement defined in the November final report MCR-74-421 was 0.87×10^{-12} ℓ/s Ar equivalent to 2.78×10^{-9} cm^3/s He. Thus, the seal amply satisfied the requirement.

3. Electrical and Mechanical

The module fit into the incubator was completely checked as seen in Figures III-11 and III-12, along with the operation of the gas sampling fitting tool. The fully assembled module, including the water, was weighed with a total mass of 434.3 gms. After connecting all the sensors and heaters into the two 9-pin connectors on the module, the resistances were checked with the results shown in Table IV-3 demonstrating test ready assembly.

Table IV-3 Module Connector Checkout

Connector	Pin No.	Color Code	Item	Resistance, Ω
Power	1 4	Brown Yellow	Injector No. 1	18.7
	2 4	Red Yellow	Injector No. 2	16.5
	3 4	Orange Yellow	Injector No. 3	17.6
	5 8	Green Grey	Cap Heater	17.5
	6 8	Blue Grey	Gas Line Heater	148
	7 8	Violet Grey	Cell Wall Heater	17.4
	0 8	Black Grey	Cell Center Heater	284
Sensor	1 4	Brown Yellow	Injector No. 1 Switch	0
	2 4	Red Yellow	Injector No. 2 Switch	0
	3 4	Orange Yellow	Injector No. 3 Switch	0
	5 8	Green Grey	Cap Sensor	546
	6 0	Blue Black	Ice Sensor	545
	7 8	Violet Grey	Cell Wall Sensor	544

V. MASS SPECTROMETER PROTOTYPE

The direction of this task has been modified according to agreement with the NASA technical monitor at no change in cost but with a considerable advantage to the overall USMLD development program. Instead of sponsoring a mass spectrometer design study at the University of Minnesota as originally planned, the revised program consists of transferring the Viking Upper Atmosphere Mass Spectrometer (UAMS) prototype instrument (Figure V-1) to the USMLD contract and modifying it to be suitable for use with the USMLD engineering model.

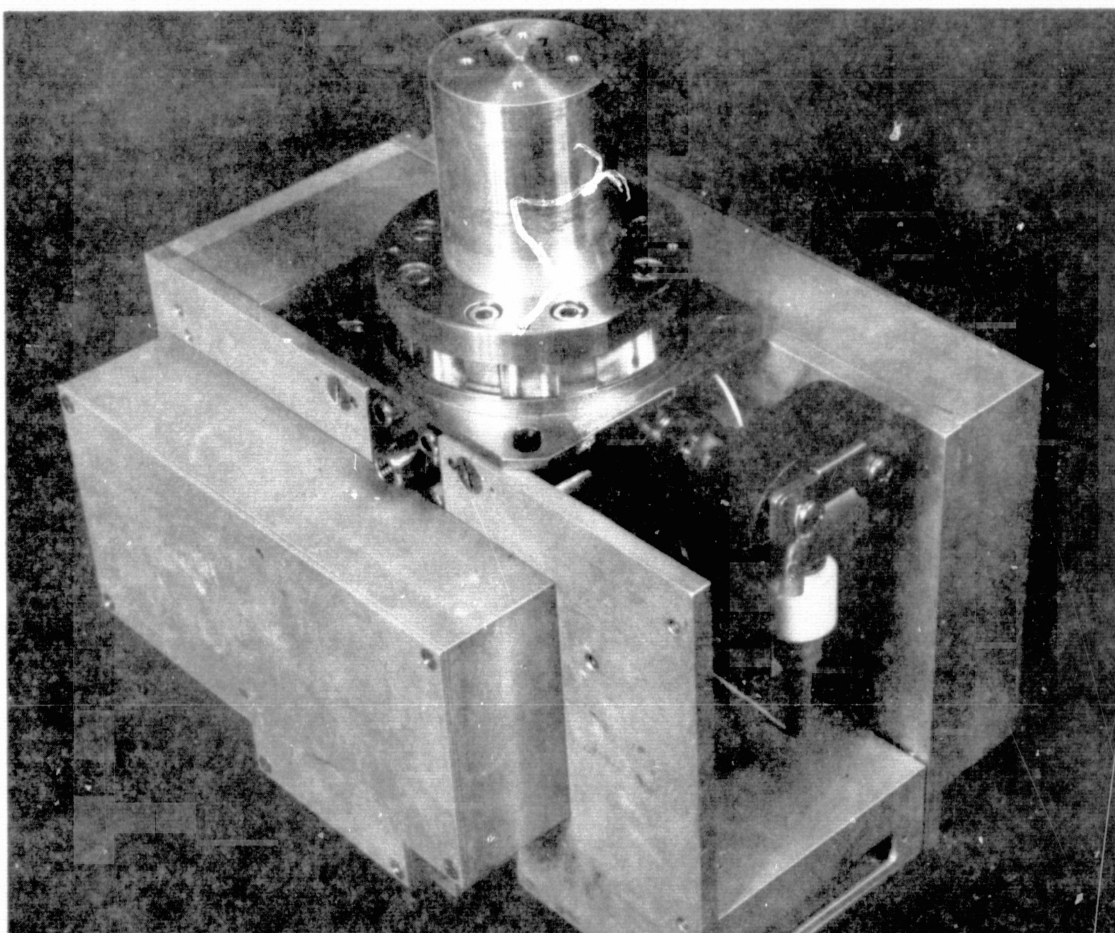


Fig. V-1
Engineering Model of the Viking '75 Upper Atmosphere Mass Spectrometer (UAMS)

Agreement was obtained from the Viking project for transferal of the UAMS instrument to this contract and the Property Transfer was effected. A work order has been issued to the University of Minnesota to rebuild the collector system and work is progressing on the hardware. It is anticipated that this phase of modification will be completed within a reasonable time after submission of this report.

The original collector system consisted of dual Faraday collectors which feed into the electrometer module. The modification consists of rebuilding the entire collector housing in order to install a dual pulse counting, and Faraday screen system at collector slits with a mass ratio of 8 to 1.

The pulse counting detectors are spiraltron type continuous dynode electron multipliers. These are placed behind 50% transmission grids which serve as Faraday collectors. With this arrangement, the instrument will cover mass numbers 1 through 8 with the spiraltron No. 1 and Faraday screen No. 1 while it will simultaneously scan masses 8 through 64 with spiraltron No. 2 and screen No. 2. The spiraltron detectors are being mounted in holders fabricated from Corning machinable glass ceramic.

Tentative interface definitions for the mass spectrometer subsystem have identified the locations of the interfaces between Martin Marietta and the University of Minnesota as illustrated in the schematic diagram of the mass spectrometer subsystem in Figure V-2.

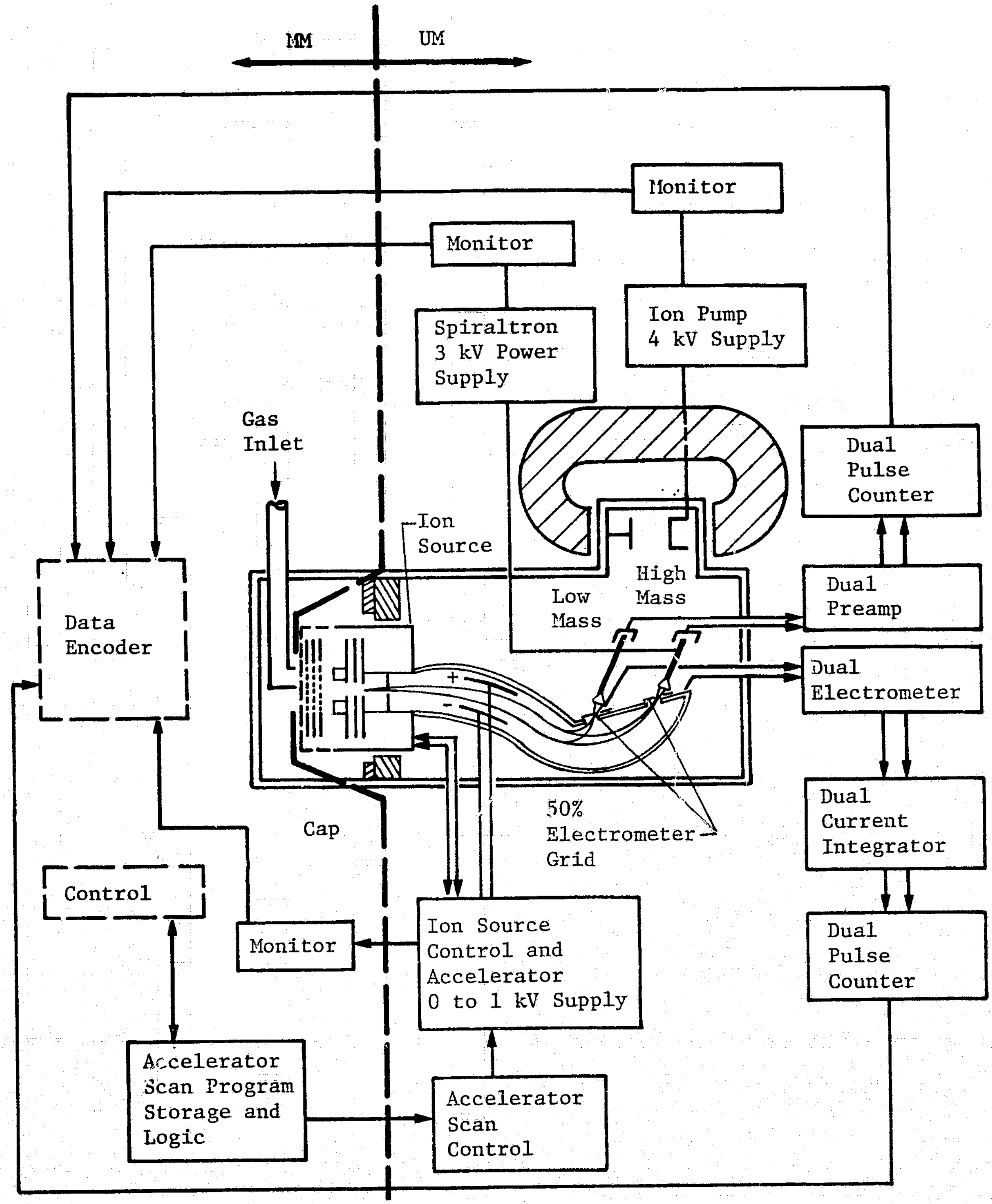


Fig. V-2
Mass Spectrometer Subsystem and Interfaces

VI. ELECTRONICS SYSTEM CONCEPTS

The development efforts of the Unified System have thus far concentrated more heavily on mechanical system and component development than on the electronic aspects. Electronic control systems were developed in the past for operation of the soil distribution system and seal drive system and during this program for the thermal control of a module. In addition, most of the mass spectrometer control electronics developed for the Atmospheric Explorer experiment are directly applicable to the Unified System. However, other circuits received no design attention. At the present time, an overall look at the electronics required for the Unified System is presented. All the principal electronic subsystems are identified in Figure VI-1 with a further definition of each of these subsystems shown in Figure VI-2 through VI-6, as well as Figure V-2.

Three concepts for the part of the thermal control subsystem to operate the test cell modules are given in Figures VI-7 through VI-9. These are identified to illustrate the tradeoff considerations in locating the module thermal control components. Some of the tradeoff considerations are summarized in Table VI-1. In Concept 3, all the circuits are constructed in hybrid packages and contained in the module itself. In Concept 3, they are all located in the basic electronics module. Concept 2 is halfway between the other two with all the heater control circuits located in the incubator box, but not in the modules. This reduces the large number of wires Concept 1 requires between the electronics module and the incubator. The choice among these three concepts should be the subject of a future study based on experience gained in operating the thermal control breadboard identified in Section III-B.

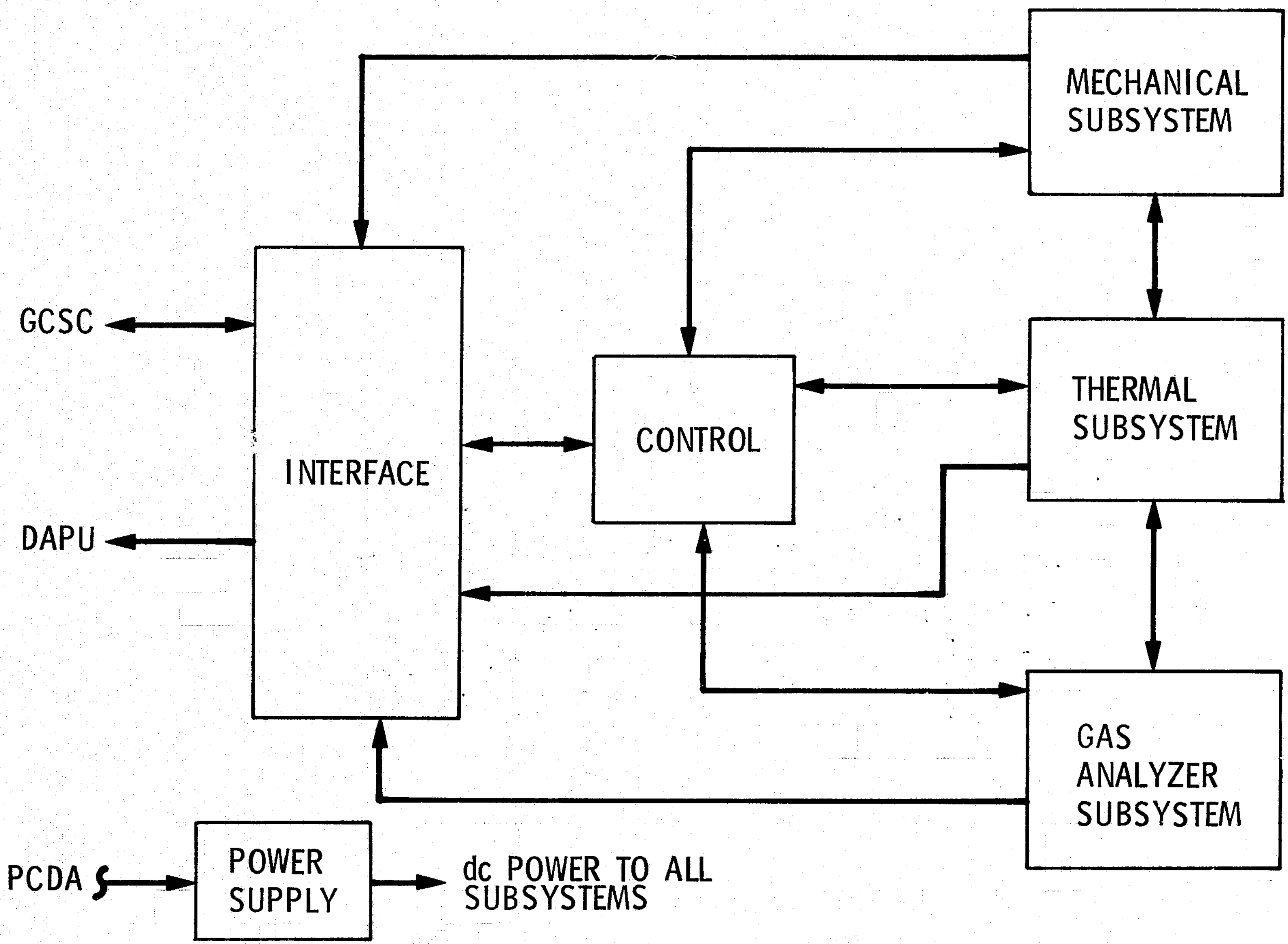


Fig. VI-1
USMLD Electronics Block Diagram

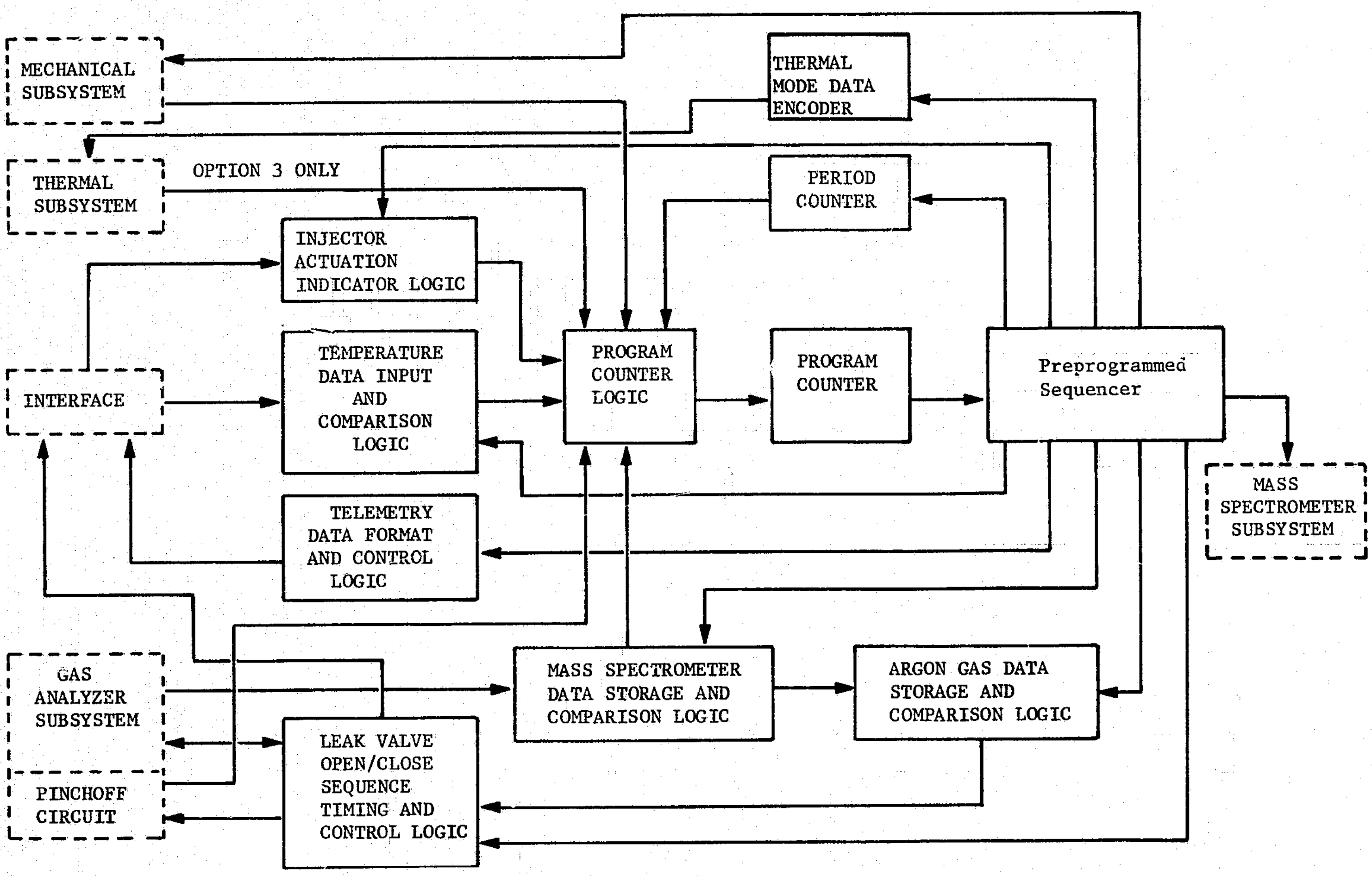


Fig. VI-2
Control Subsystem

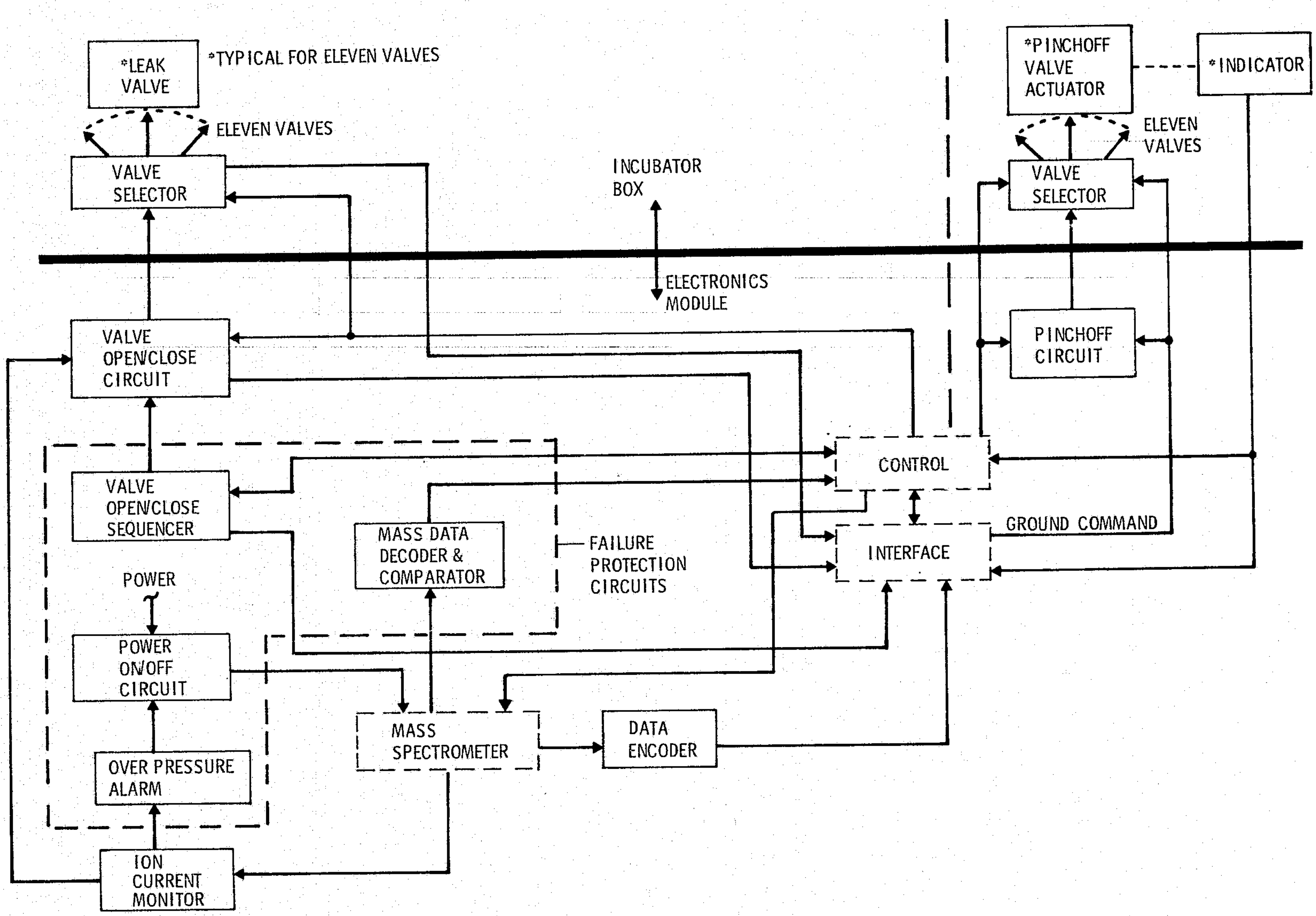


Fig. VI-3 Gas Analyzer Subsystem

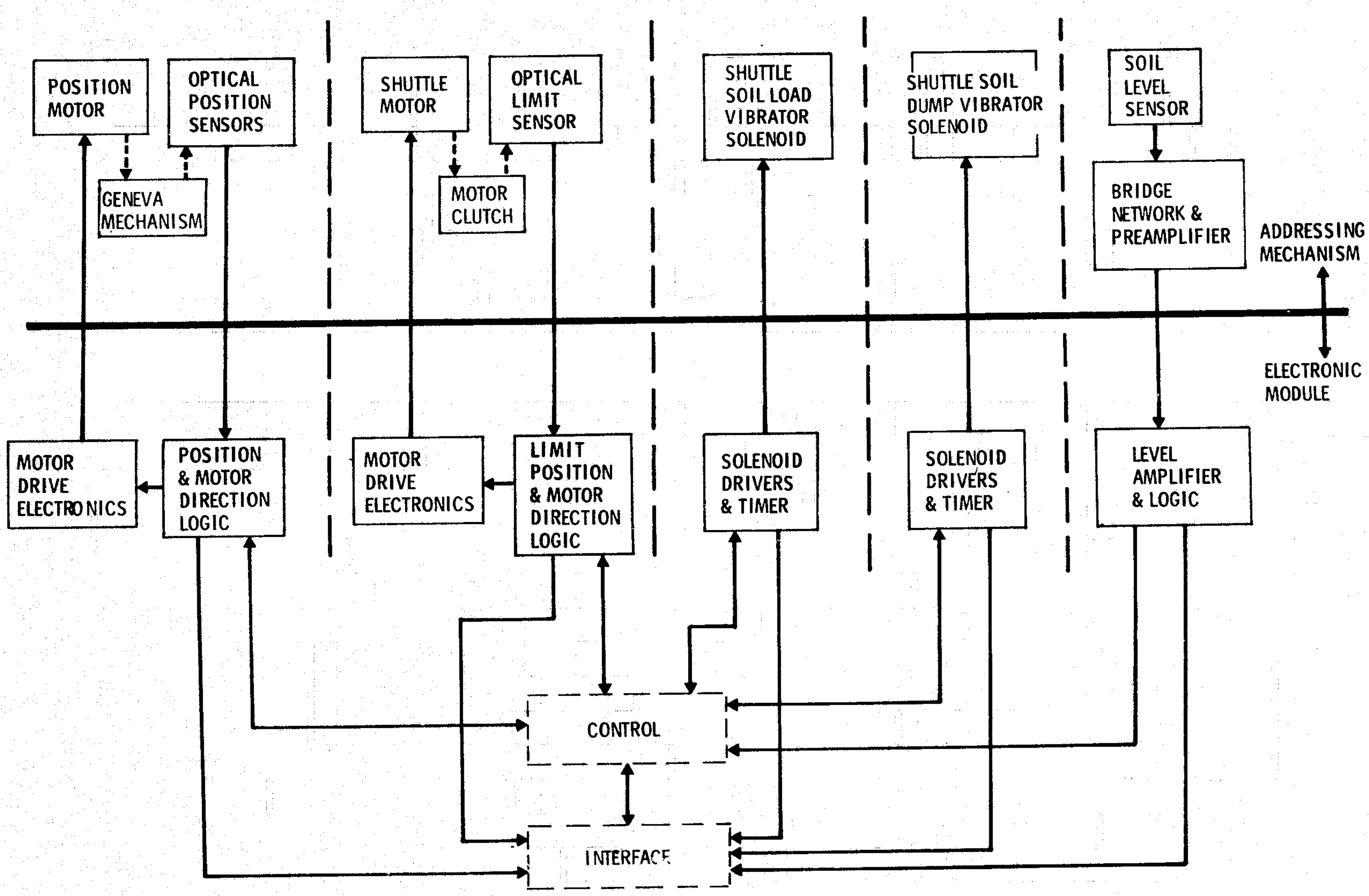


Fig. VI-4 Mechanical Subsystem-Soil Distribution

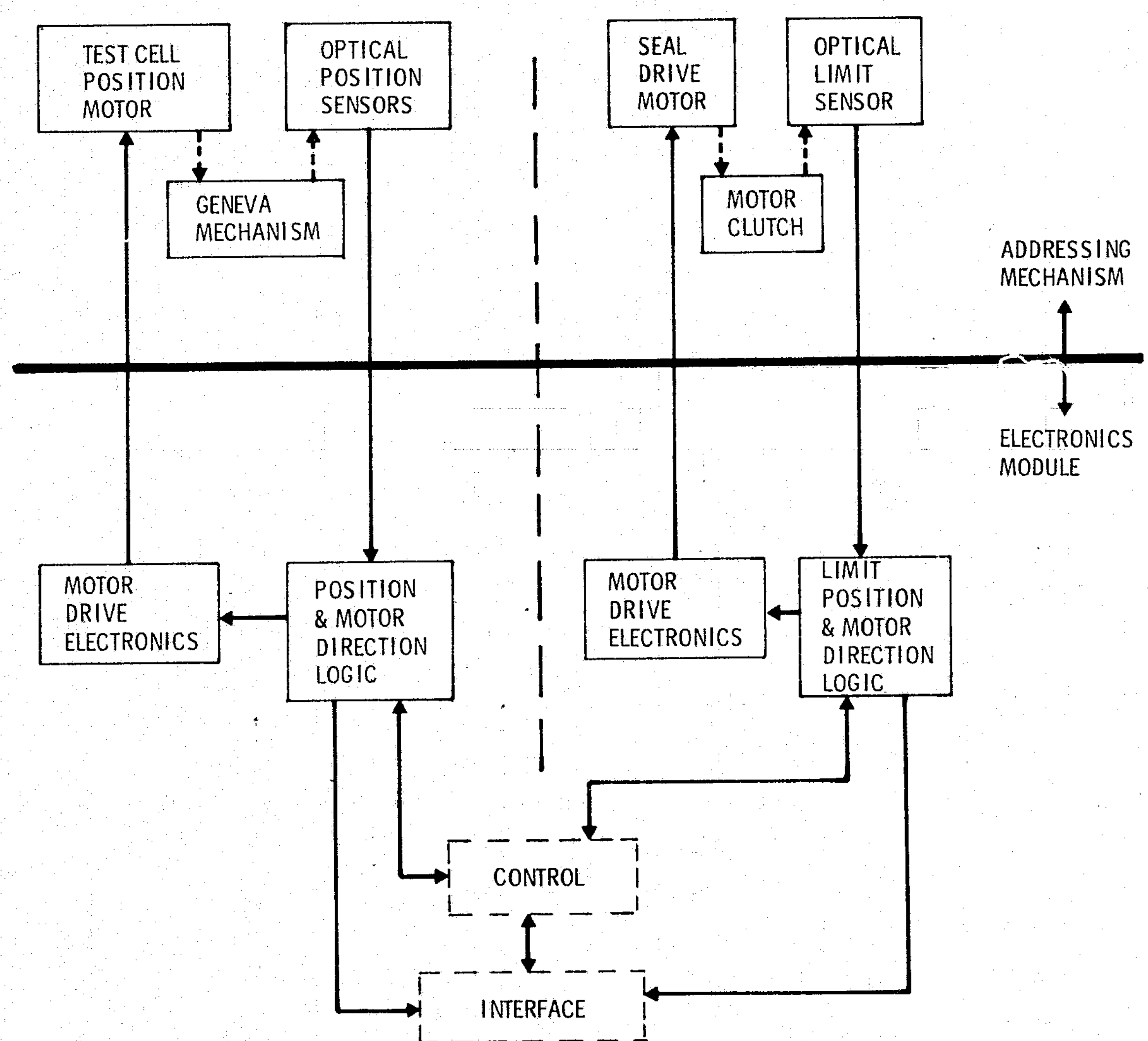


Fig. VI-5 Mechanical Subsystem-Test Cell Seal

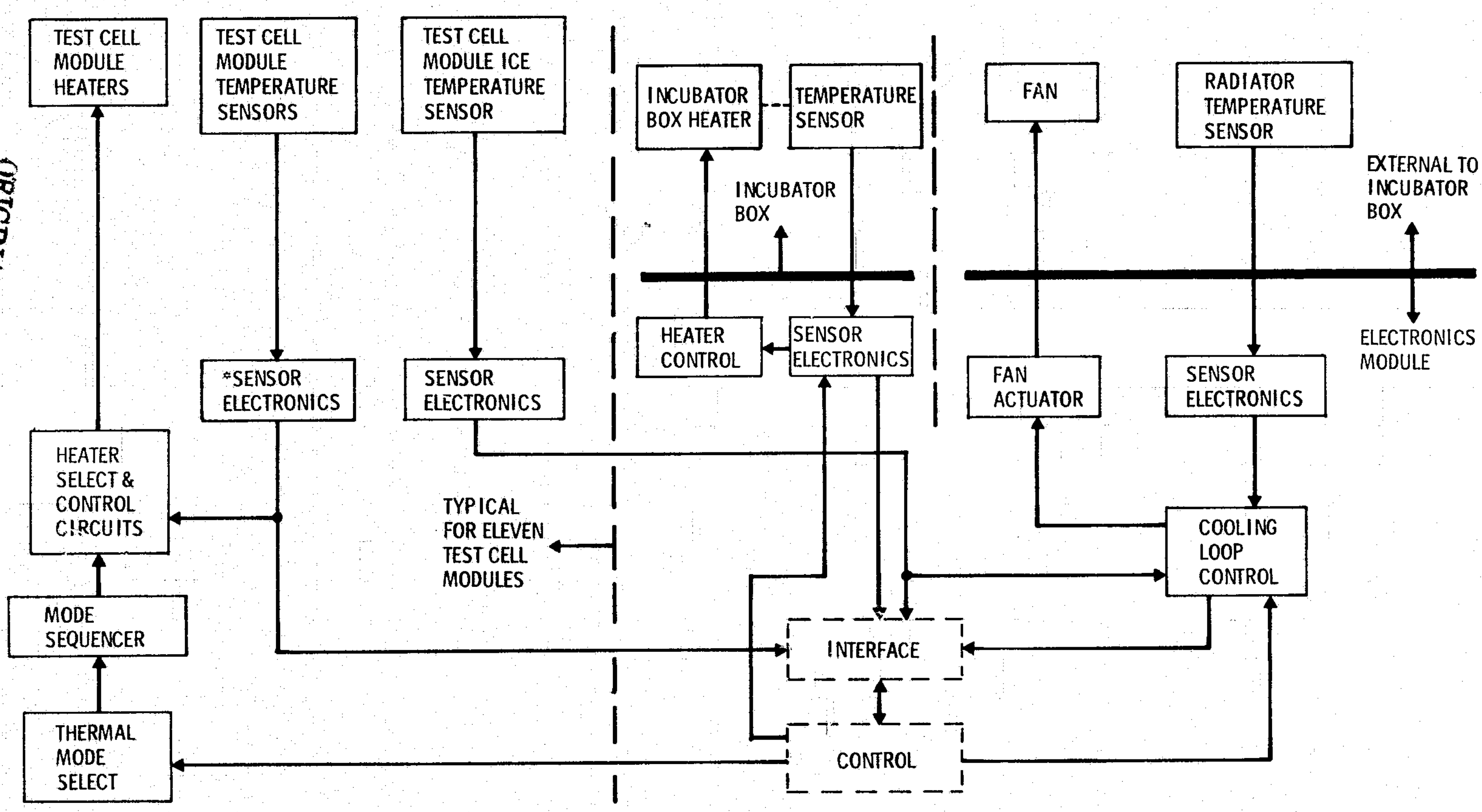


Fig. VI-6 Thermal Subsystem

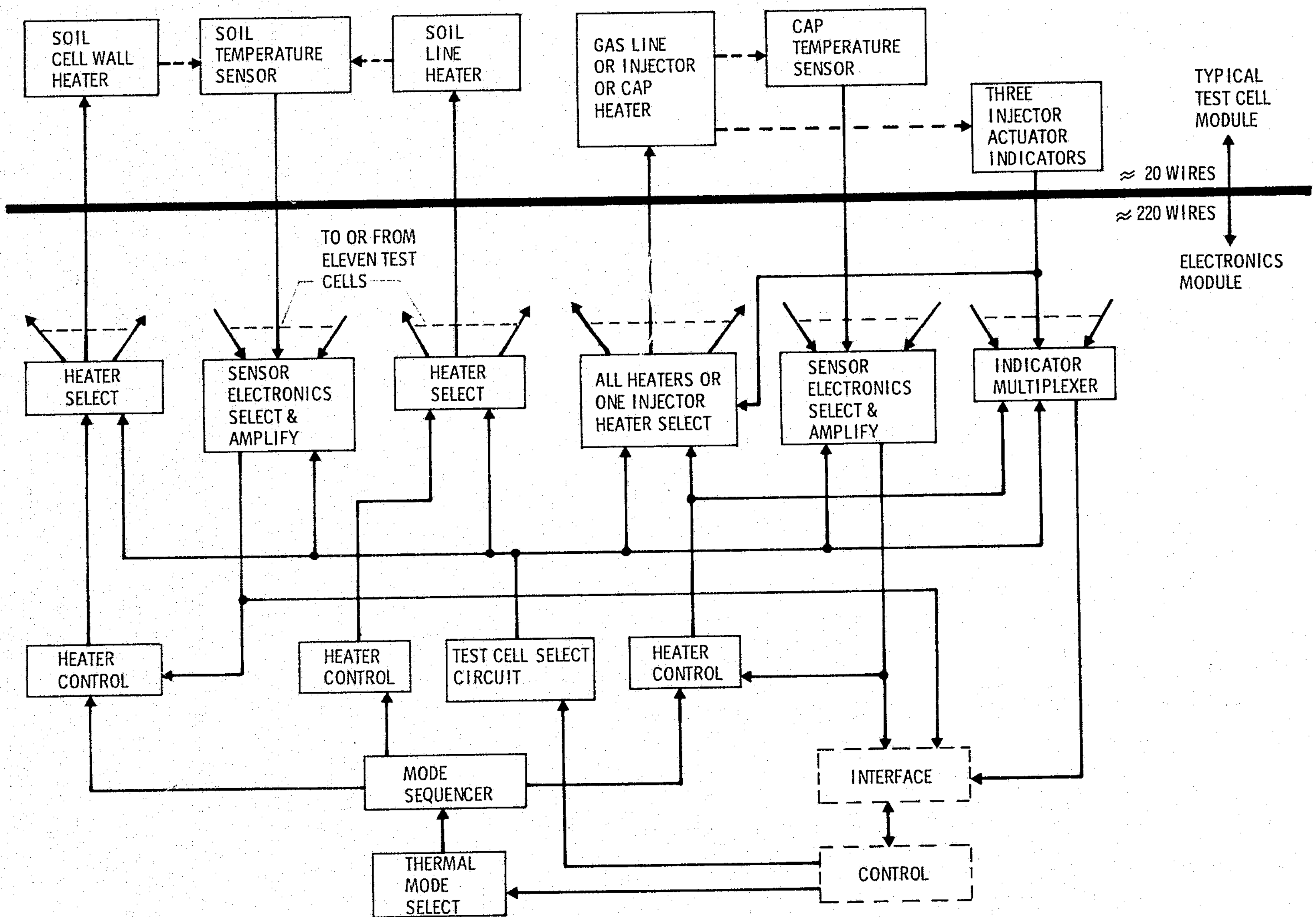


Fig. VI-7
Test Cell Module Thermal Subsystem Concept 1 (All Circuits in Electronics Module)

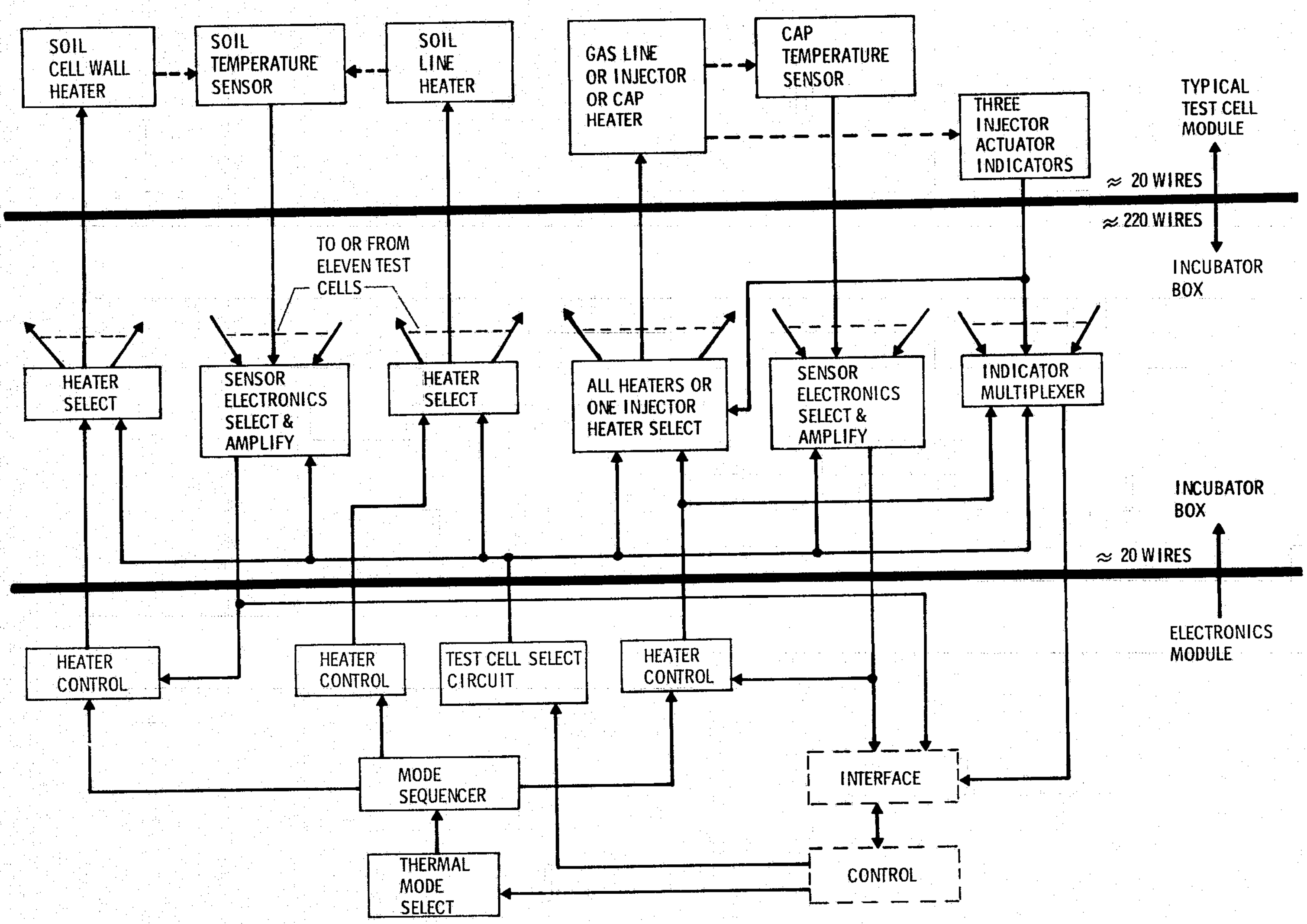


Fig. VI-8
Test Cell Module Thermal Subsystem Concept 2 (Test Cell Selection Circuits in Incubator Box)

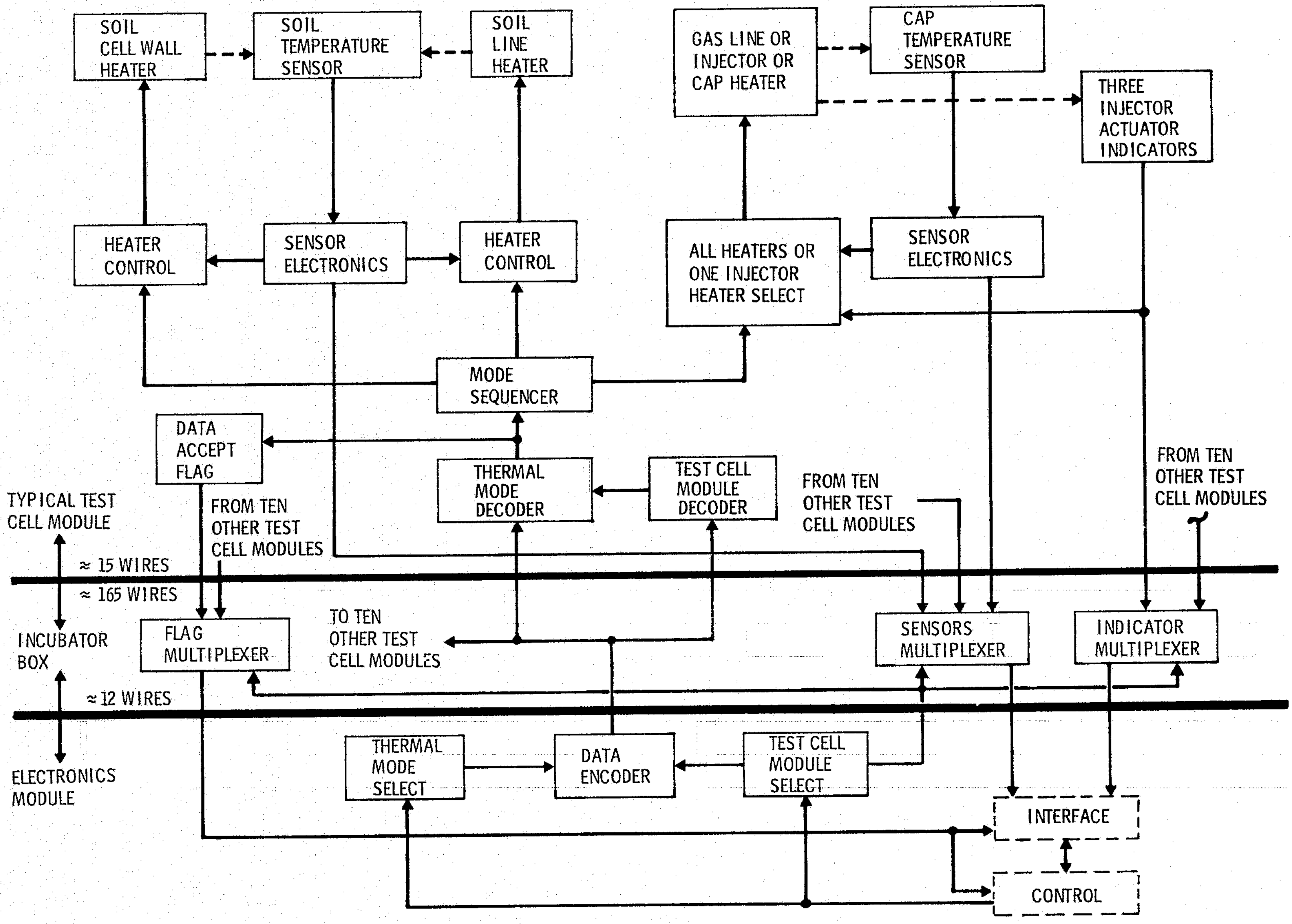


Fig. VI-9
Test Cell Module Thermal Subsystem Concept 3 (Control Circuits in Each Test Cell Module, Multiplexers in Incubator Box)

Table VI-1
Tradeoff Criteria for Test Cell Module Thermal Subsystem Concepts

- o CONCEPT 1 -- ALL CIRCUITS LOCATED IN ELECTRONICS MODULE
- o CONCEPT 2 -- TEST CELL SELECTION CIRCUITS LOCATED IN INCUBATOR BOX
- o CONCEPT 3 -- CONTROL CIRCUITS LOCATED IN EACH TEST MODULE, MULTIPLEXERS IN INCUBATOR BOX

	CONCEPT 1	CONCEPT 2	CONCEPT 3
ELECTRONICS PARTS COUNT	MINIMUM	MINIMUM	MAXIMUM (TEST CELL HYBRID CIRCUITS POSSIBLE)
INCUBATOR BOX ELECTRONICS HEAT DISSIPATION	MINIMUM	SOME	MAXIMUM
ELECTRONICS MODULE INTERFACE WIRES	MAXIMUM $\approx$ 154 WIRES	MINIMAL $\approx$ 20 WIRES	MINIMUM $\approx$ 12 WIRES
INDIVIDUAL TEST CELL MODULE INTERFACE WIRES	MAXIMUM $\approx$ 20 WIRES	MAXIMUM $\approx$ 20 WIRES	MINIMUM $\approx$ 15 WIRES
TEMPERATURE SENSOR WIRE LENGTH	VERY LONG	LONG	VERY SHORT
REDUNDANT CIRCUITS	NONE	NONE	CIRCUIT FOR EACH TEST CELL
TEST CELL MODULE "STAND ALONE" TESTING	TEST INDIVIDUAL COMPONENTS ONLY	TEST INDIVIDUAL COMPONENTS ONLY	TEST COMPLETE THERMAL MODES